The WELDING JOURNAL

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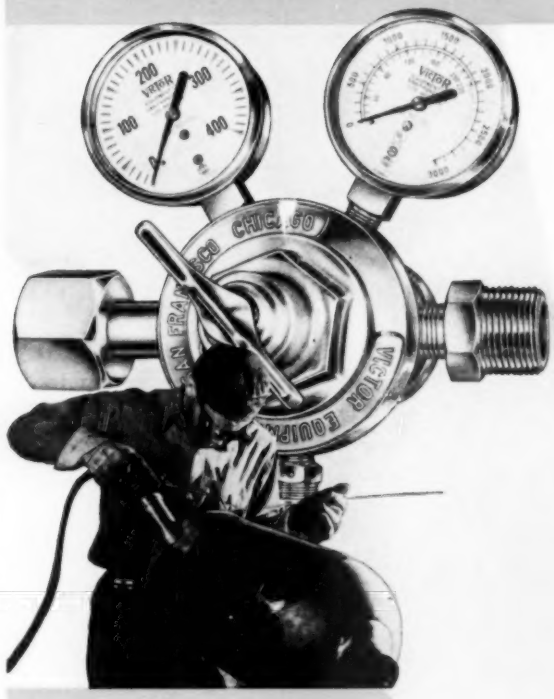

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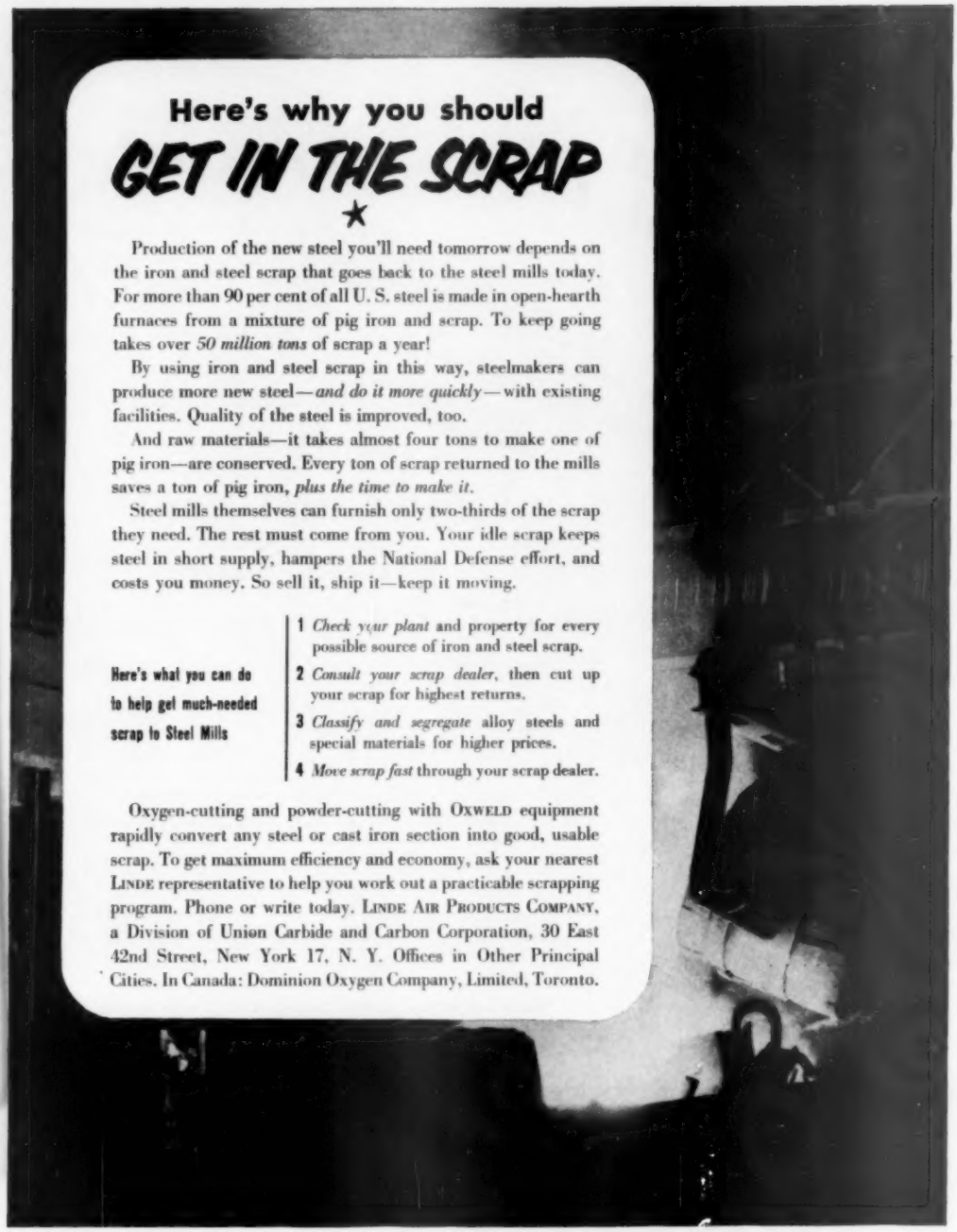

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The WELDING JOURNAL

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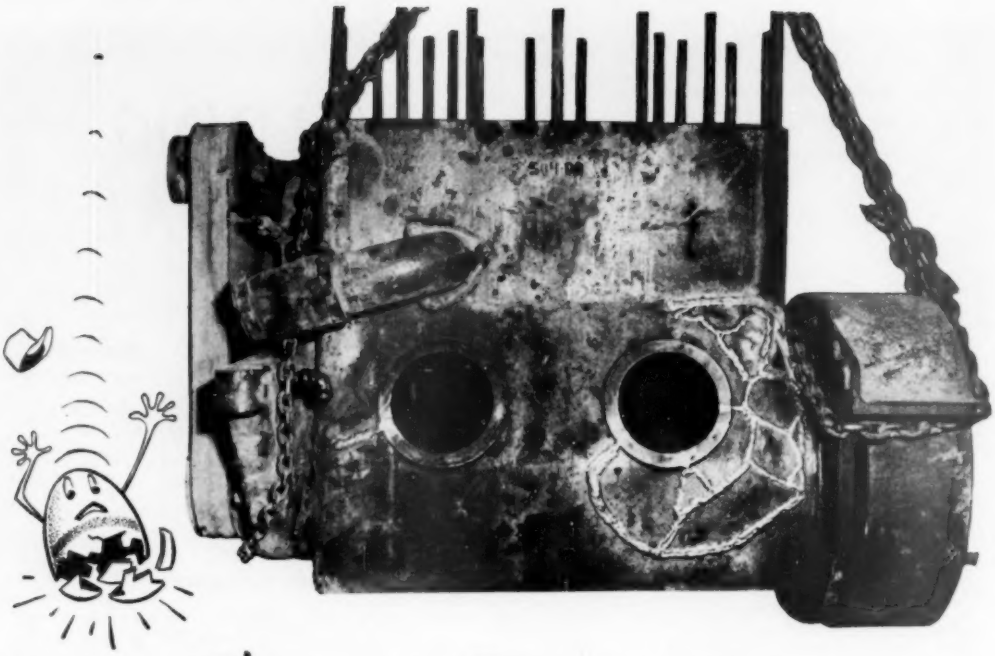

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The WELDING JOURNAL

volume 30 August 1951 number 8

Resistance Welding of Nickel and High-Nickel Alloys

Complete practical information and engineering data on spot, projection seam and flash welding, and resistance brazing

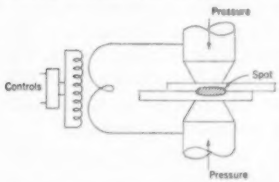
by R. M. Wilson, Jr.

1. INTRODUCTION

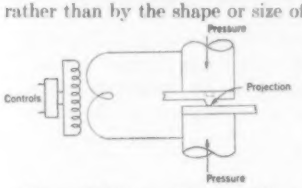
ALL resistance-welding processes employ the use of large electric currents and relatively high unit pressures. The passage of current generates heat in the parts to be welded in direct proportion to the internal electrical resistance of the material. Thus the name. The pressure serves to keep the parts in contact before and during the welding and also forges the resulting weld during and after solidification of the molten metal.

The resistance welding processes which will be discussed in this paper are Spot Welding, Projection Welding, Seam Welding, Flash Welding and Resistance Brazing.

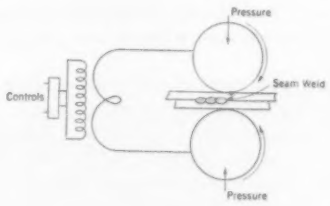
Spot Welding. Spot welding is a process of joining two or more overlapping sheets by local fusion of a small area or spot. Two, dome-pointed, copper-alloy electrodes contact either side of the overlapped sheets under known loads produced by spring or air pressure. A relatively large, low-voltage, electric current is passed through the electrodes and the work for a short interval of time. A small volume of material, centered on the faying (contact) surfaces of overlapped portion, but not extending to the outside surfaces is fused by the current and forged by the pressure



Projection Welding. Projection welding is a process of joining similar to spot welding. The main difference is that the location and size of weld produced is determined by embossments or projections on the parts rather than by the shape or size of the electrode tip in contact with the surface. This process is used mainly to join small pieces together or to join small hardware to large parts.



Seam Welding. Seam welding is a joining process similar to spot welding. The pointed spot welding tips are replaced by wheels and a series of overlapping spots produces a gas-tight seam of a desired length.

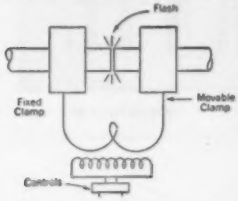


Flash Welding. Flash welding is a joining process applied to rod, bar, pipe and sheet to produce a butt joint. The work is clamped in current-carrying jaws of the machine and separated prior to turning on the current. After the current is turned on, the two parts are brought together at a predetermined rate such that discontinuous arcing occurs between the two parts to be

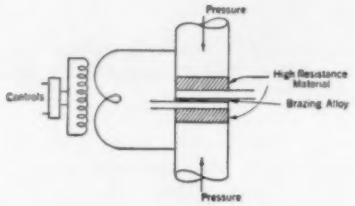
R. M. Wilson Jr., is connected with Technical Service, Development and Research Division of the International Nickel Co. Inc., New York.

Copies of this paper may be obtained from the International Nickel Co. Inc., 17 Wall St., N. Y. 5, by asking for Technical Bulletin T-33.

joined. This arcing produces violent expulsion of small particles of metal (flashing) and produces a positive pressure in the weld area which excludes air and minimizes oxidation. When sufficient heat has been developed by flashing, the parts are brought together under heavy pressure so that all fused and oxidized material is extruded from the weld.



Resistance Brazing. Resistance brazing is a brazing process accomplished on a spot or seam welder employing high-resistance electrodes faced with carbon, tungsten or molybdenum to generate heat. A silver brazing alloy is usually preplaced in strip or powder form.



2. GENERAL CONSIDERATIONS

Nickel and the high-nickel alloys can be joined easily to themselves and to many other ferrous and nonferrous metals and alloys by the resistance welding processes with equipment in common use throughout industry.

2.1 *Chemical Analysis, Mechanical Properties and Physical Properties*

Table 2.1 lists the nominal chemical analysis, the average mechanical properties and the average physical properties of the nickel and high-nickel alloys which will be discussed. For convenient reference, similar data are listed for carbon steel, stainless steel, aluminum and copper.

There is a wide range of electrical resistance in the nickel alloys varying from a low of 50 ohms per circular mil foot for low-carbon nickel to a high of 750 ohms per circular mil foot for Inconel "X."* This electrical property is the most important to resistance-welding processes since the heat generated by a passage of current is directly proportional to this internal resistance. The coefficients of thermal expansion of the nickel alloys are fairly low, approaching that of carbon steel. Warpage due to welding is of the same magnitude as that encountered with carbon steel. The mechanical properties of the high-nickel alloys range upward from that of low-carbon nickel which is not too different from carbon steel. In general these high-nickel alloys retain their high mechanical properties at elevated temperatures. Therefore, there is a need for higher unit pressures than is necessary for carbon steel.

* Reg. U. S. Pat. Off.

2.2 *Cleanliness Considerations*

In resistance welding any metallic material or alloy, the presence of foreign matter on the surface such as oxides, oil, grease, paint and dirt is a source of difficulty due to the high resistance of such material to the passage of an electrical current. The need for cleanliness before attempting to weld nickel and the high-nickel alloys cannot be overemphasized.

Nickel and high-nickel alloys are susceptible to sulphur embrittlement when in contact with sulphur-containing materials at elevated temperatures. Oils, greases, drawing compounds and marking pencil marks often contain sufficient sulphur compounds to cause embrittlement at the temperatures produced during resistance welding. Before welding, all foreign substances should be removed from the surfaces with carbon tetrachloride, petroleum spirits, vapor degreasing or caustic degreasing.

All metals oxidize in air. The oxide film so formed has high unit electrical resistance, but the total resistance of an oxide film is largely dependent on its thickness. The oxide which forms on nickel and high-nickel alloys when they are exposed to clean air at room temperature is very thin, transparent and increases in thickness at a very slow rate. Due to its extreme thinness, the resistance is negligible so that it is seldom necessary to institute an oxide-removing operation before resistance welding on bright nickel alloy sheet or strip as received from the mill.

Long storage of nickel and nickel alloys in contaminated industrial atmospheres will produce oxide films of greater thickness which are not transparent, but which tend to darken the surface appearance. Such oxide films have appreciable resistance and must be removed before attempting to resistance weld. When nickel and high-nickel alloys are heated in an oxidizing atmosphere, a heavy brown oxide film is formed. This film has extremely high electrical resistance and must be removed before welding. Heavy oxide films will cause local hot spots resulting in die burns (flash welding) or surface burning and flashing, low electrode life and porosity in welds (spot, seam and projection welding).

Chemical pickling will be found to be the most satisfactory method of removing oxides on nickel and the nickel alloys prior to production welding. Table 2.2 gives the recommended pickling procedures for the type of oxide present and for the material to be pickled. Further details are given in another publication.*

Oxide removal can be accomplished mechanically by grinding, sanding or shot blasting. This method is satisfactory for small sample quantities or for spot clean-

* *Pickling Inco Nickel Alloys*, Technical Bulletin T-21. The International Nickel Co., Inc., New York, N. Y.

TABLE 2.1

Chemical Composition, Mechanical Properties and Physical Constants of Nickel and Nickel Alloys

Steel, Stainless Steel, Copper and Aluminum included for reference

Material	Approximate Composition (Essential Elements) per cent	Form and Condition	AVERAGE MECHANICAL PROPERTIES				AVERAGE PHYSICAL CONSTANTS									Material
			Yield Strength (0.2% offset) 1000 psi.	Tensile Strength 1000 psi.	Elongation in 2 in., per cent	Hardness Brinell	Density lb./cu. in.	Specific Gravity	Melting Point °F.	Specific Heat (32°–212° F.) Btu./lb./° F.	Thermal Expansion Coefficient (32°–212° F.) 10^{-6} in./in./° F.	Thermal Conductivity (32°–212° F.) Btu./sq. ft./hr./° F./in.	Electrical Resistivity (32° F.) ohms/cir. mil ft.	Tensile Modulus of Elasticity 10^6 psi.	Torsional Modulus of Elasticity 10^6 psi.	
Monel (wrought)	Ni —67 Cu —30 Fe — 1.4 Mn— 1	Annealed Hot-rolled Cold-drawn Cold-rolled[4]	35 50 80 100	75 90 100 110	40 35 25 5	125 150 190 240	0.319	8.84	2370–2460	0.13	7.8	180	290[1]	26	9.5	Monel (wrought)
"K" Monel	Ni —66 Cu —29 Al — 2.75 Fe — 0.9	Hot-rolled Hot-rolled[2] Cold-drawn Cold-drawn[3]	45 110 85 115	100 150 115 155	40 25 25 20	160 280 210 290	0.306	8.47	2400–2460	0.13	7.8	130	350	26	9.5	"K" Monel
Nickel (wrought)	Ni —99.4	Annealed Hot-rolled Cold-drawn Cold-rolled[4]	20 25 70 95	70 75 95 105	40 40 25 5	100 110 170 210	0.321	8.89	2615–2635	0.11	7.2	420	57	30	11	Nickel (wrought)
Low Carbon Nickel	Ni —99.4 C — 0.02 max.	Annealed	15	60	50	90	0.321	8.89	2615–2635	0.11	7.2	420	50	30	11	Low Carbon Nickel
Duranickel	Ni —93.5	Hot-rolled Hot-rolled[2] Cold-drawn Cold-drawn[3]	50 130 90 135	105 170 120 175	35 15 25 15	180 320 220 340	0.298	8.26	2615–2635	0.104	7.1 7.3[3]	138 137[3]	280[1] 260[3]	30	11	Duranickel
Inconel (wrought)	Ni —77.0 Cr —15.0 Fe — 7.0	Annealed Hot-rolled Cold-drawn Cold-rolled[4]	35 60 90 110	85 100 115 135	45 35 20 5	150 180 200 260	0.307	8.51	2540–2600	0.11	6.4	104	590	31	11	Inconel (wrought)
Inconel "X"	Ni —73 Cr —15 Fe — 7 Ti — 2.5	Annealed Hot-rolled[3]	50 120	115 180	50 25	200 360	0.300	8.30	2540–2600	0.105	7.6	102	750	31	11	Inconel "X"
Carbon Steel SAE 1020	Fe —Bal. Mn—0.45 Si —0.25 C —0.20	Annealed Hot-rolled Hardened[13] Hardened[14]	40 45 80 62	60 69 104 90	35 31 6 22	130 146 205 175	0.284	7.86	2760	0.107	6.7	360	60	30	11.6	Carbon Steel SAE 1020
Stainless Steel Types 321 and 347	Fe —Bal. Cr —18 Ni —10 C —0.10 max. Ti[19]—4 x carbon min. or Cb[20]—10xcarbon min.	Annealed Cold-rolled	30 100 up to 120	85 up to 150	50 5	160 300	0.286	7.92	2550–2600	0.12	9.3	110	435	28		Stainless Steel Types 321 and 347
Alcoa 2S	Al —99 plus	Annealed Cold-rolled[5] Cold-rolled[4]	5 14 21	13 17 24	45 20 15	23 32 44	0.098	2.71	1190–1215	0.22	13.9	1540 1510	16.2 16.8	10.0	3.8	Alcoa 2S
Copper	Cu —99.9 plus	Annealed Cold-drawn Cold-rolled[4]	10 40 48	32 45 52	45 20 5	42 90 100	0.322	8.92	1980	0.092	9.3	2700	10.4	16		Copper

[1] Annealed.
[2] Age-hardened.
[3] Hard temper.
[5] Half-hard temper.
[13] Water-quenched, drawn at 200° F.
[14] Water-quenched drawn at 1000° F.
[19] In type 321 only.
[20] In type 347 only.

ing of large pieces, but it is expensive in labor and requires considerable supervision to obtain uniform results in production. Occasionally, special blasting equipment such as Hydroblast† will be found useful. Wire brushing is not considered satisfactory because of the tenacious nature of oxide films on the nickel alloys.

2.3 Selection of Process

Resistance-welding processes are well suited to the high production requirements of mass production. Welds are made in machines at a very rapid rate by operators who can quickly acquire the necessary skill to load and unload a machine, and push a button or press a foot switch. Therefore, the labor cost per weld is extremely low, particularly when compared with other joining methods such as arc welding, gas welding, soldering, riveting or bolting. Resistance-welding machines, on the other hand, are expensive as compared with the cost of equipment for other methods of joining. In order to economically justify a resistance-welding process, a large volume of identical or similar joints is required to obtain the low-unit labor cost and also a reasonably low-unit machine cost.

† Reg. U. S. Pat. Off., Pangborn Corp., Hagerstown, Md.

TABLE 2.2
Pickling Recommendations for Nickel and High-Nickel Alloys[a]

Formula to be used for the following types of Oxides

Alloy	Light Tarnish	Reduced Oxide	Heavy Oxide
Nickel	3	4	5(c) and 3(b)
Duranickel	3	4	5(c) and 3(b)
Monel	1 and 2(b)	4	5 and 6(b)
"K" Monel	1 and 2(b)	4	5 and 6(b)
Inconel	—	—	7
Inconel "X"	—	—	7 or 7A

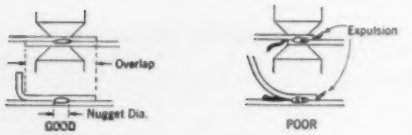


Table 3.31. More overlap than necessary may be slightly more costly in material but will be much easier on the operator in locating the spot weld since this is usually done by eye rather than by jig. Less than the recommended overlap will promote slower welding

Make-up of Formulae

	1	2	3	4	5	6	7	7A
Water, gal.	1	1	1	1	1	1	1	3
Nitric Acid (38° Bé), gal.	1	1	2½	—	—	—	1	1
Sulfuric Acid (66° Bé), gal.	—	—	1½	¾ pt.	—	0.1	—	—
Hydrochloric Acid (20° Bé), gal.	—	—	—	—	½	—	—	—
Hydrofluoric Acid (40%), gal.	—	—	—	—	—	—	1¼ pt.	0.2
Sodium Chloride, lb.	½–¾	—	¼ (d)	1	—	—	—	—
Sodium Nitrate (Crude), lb.	—	—	—	½	—	—	—	—
Sodium Dichromate, lb.	—	—	—	—	—	1.1	—	—
Cupric Chloride, lb.	—	—	—	—	¾	—	—	—
Temperature °F.	70–100	70–100	70–100	180–190	180	70–100	70–100	120–140
Time	Not over 5 sec.	Not over 5 sec.	5–20 sec.	30–90 min.	20–40 min.	5–10 min.	15–90 min.	15–90 min.
Container Materials	Crocks, Glass, Ceramic	18–8 Stainless, Glass, Ceramic	Crocks, Glass, Ceramic	Crocks, Glass, Ceramic	Crocks, Glass, Ceramic, Brick	Crocks, Glass, Ceramic, Rubber	Carbon Brick	Carbon Brick

Notes: (a) All work should be degreased prior to pickling, and should be neutralized as a last operation in a 1-2 percent (vol.) ammonia solution.
(b) Hot water (180°F.) rinse between dips.
(c) Will require 1 to 2 hours.
(d) Allow to cool before adding salt.
Safety Note: Fumes from these pickle solutions are strongly irritant. Ventilating hoods should be employed.

The application of a resistance-welding process to a design which primarily considered another joining process such as riveting or arc welding will seldom be economical or satisfactory. In order to obtain maximum benefits, specific requirements of the resistance-welding process should be considered in the early stages of design.

Spot welding, seam welding and most projection welding applications can be done only on a lap-type joint. This limits these processes to use on relatively thin sheet and strip. The lap-type joint has an inherent crevice between sheets which acts as a stress raiser in applications where fatigue is a factor. The crevice is also a source of trouble where corrosion is a factor. Flash welding produces a butt-type joint with no inherent crevice. Therefore, from corrosion and fatigue standpoints, flash welds are superior to spot, seam or projection welds.

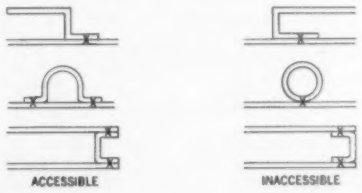
3. SPOT WELDING

3.1 Design Considerations

The most economical application and the best overall results can be secured when the design has been made specifically for spot welding. The following factors should be kept in mind when designing for spot welding.

3.11 Overlap. A sufficient amount of *flat* overlap must be provided to contain the spot weld. The minimum recommended overlap for each gage is shown in since the operator must be more careful in locating his spots. In addition, expulsion of metal will result and the weld will be low in strength and contain porosity. Frequently, a finishing operation must be added where expulsion has occurred because of inadequate overlap.

3.12 Accessibility. Spot welds should be placed in a structure so that they can be easily reached with stand-



ard equipment. Inaccessible welds increase greatly the cost of welding labor, special tools and maintenance charges.

3.13 Flatness. Formed parts when assembled must be in contact in those areas to be spot welded. The spot-welding machine is not a forming machine. If a portion of the machine pressure is utilized to bring the parts into intimate contact, then there will be insufficient pressure to contain the molten weld metal. Expulsion will result. Inadequate forging pressure after welding may lead to cracking troubles.

3.14 Jigging. Most jigs and fixtures for spot welding assembly can be rather simple affairs which are light in weight and quickly used. It is well known that the

largest portion of spot welding time is utilized in assembly of the parts in the fixture, the moving of the assembly to the machine and the removal of the welded assembly from the jig. The actual welding is but a small portion of the total time. Therefore, it is important to analyze the welding jig and see that it does the job properly but is not unduly heavy or cumbersome. Frequently, the designer can help by making parts which are self-locating or by specifying locating holes.

3.15 Spot Spacing. If spots are located too close to each other, a large portion of the welding current to produce the second or subsequent spots will shunt through the spot or spots already made. This will result in the formation of a small nugget or no nugget at all. The single good weld and subsequent poor welds may not be strong enough to support the load for which the structure was designed. When close spot welds are necessary, refer to Table 3.31 for minimum spacing allowable. If closer spots are required then a special machine setting for the second weld or projection welding may offer a solution. At least two welds should be employed always to attach a piece which might be subject to torsion.

3.16 Weld Strength. The shear strengths of single spot welds shown in Table 3.31J can be used in design of static structures. These values are a rounded 80% of actual tests (Column I). Shop setup tests should employ the values shown in Column I.

3.17 Fatigue Strengths. Spot welds are notoriously poor performers in structures subjected to fatigue. When a structure is to be subjected to fatigue, the design stress should not exceed 20% of the values shown in Table 3.31J. Figure 3.17 shows the results of actual fatigue tests on spot-welded specimens of Monel,* nickel, Inconel* and "K"* Monel.

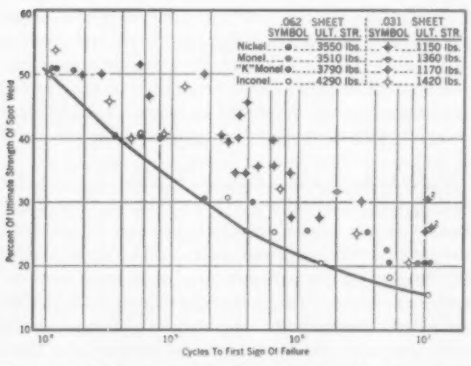


Fig. 3.17 Fatigue strength of spot welds. Minimum load 10 = 1/2% of spot strength

3.2 Equipment Considerations

3.21. Pressure. The function of pressure during spot welding is threefold.

(*a*) To provide intimate contact between electrodes and work and between the two sheets so that current can flow.

(*b*) To contain the molten nugget during current flow when high internal pressures are built up by the heat of welding.

(*c*) To provide a forging action during nugget solidification so that thermal shrinkage will not promote cracking and porosity.

Nickel and low-carbon nickel, having properties similar to steel, behave like steel. The high-nickel alloys generally are harder and stronger than low-carbon steel, particularly at elevated temperatures, and greater unit pressures are required during spot welding. For a given application, the upper limit of pressure may be determined where serious distortion and electrode mushrooming occur. The lower limit of pressure will be set by the tendency for expulsion, cracking and porosity in the weld. It is important that machines have adequate pressure capacity if they are to be used to spot weld the high-nickel alloys. Although heavy pressures are required, the majority of this pressure should be derived from spring, air or fluid pressure to minimize inertia effects when heavy masses are to be moved in very short times.

3.22 Time. The time of current flow is kept as short as possible for the given application. On very thin materials this time is held to one or two cycles of 60-cycle current, while with thicker material the time is increased. The use of very short time on heavier material requires the use of extremely high current and this results in expulsion, surface burning and inconsistent strengths. The use of too long times promotes distortion, electrode mushrooming and inconsistent weld strengths. Table 3.31 shows the recommended times for various thicknesses and for various combinations. It will be noted that the thinner member is the one governing the selection of machine settings.

Accurate timing equipment is always advisable but is imperative when short times are employed (under 5 cycles). Electronic switching devices are strongly recommended because they produce uniformly accurate times and because the time is synchronized with the welding current. Magnetic contactors can be employed when longer time cycles are used but the strength consistency of spot welds made with such equipment will not be as good as with electronic equipment.

A relatively new piece of equipment which can be employed with phase control electronic timers is called "Slope Control."* This feature permits the start of current flow at a low value and gradually builds it up to full welding current over a controlled number of cycles. Such equipment tends to reduce expulsion and makes possible the welding of dissimilar metals combinations. Stored energy machines and rectified a.-c. machines can also approximate this feature.

3.23 Current. The electrical resistance of nickel and low-carbon nickel is similar to steel while that of the

* Reg. U. S. Pat. Off.

* Reg. U. S. Pat. Off., General Electric Co.

high-nickel alloys is generally much higher than that of mild steel. See Table 2.1. The current requirements are, therefore, the same as, or somewhat less than those required for steel and a good deal less than those required for aluminum.

Current is usually the last variable to be fixed when developing a machine setting for a given job. The pressure and time are selected from a table such as Table 3.31 or from past experience, and the current is varied over a range which first produces sticking, then first-nugget formation and finally expulsion. A current is selected which is just under that which will produce expulsion but is somewhat more than the point at which first-nugget formation is produced. If this range (nugget formation to expulsion) is too narrow, then other values of pressure and time must be selected and process repeated. The object is to obtain a machine setting which will produce consistent welds despite small variations in gage thickness, surface cleanliness, electrode diameter, line voltage fluctuations and other variables.

Normally, it is not a production practice to measure the finite value of the current employed. A record of the tap setting and phase control setting employed will be sufficient usually to enable the operator to obtain this same setting in the future. However, such a record will not enable the operator to set up the job on any other machine nor will it be very helpful if large variations in machine throat are frequently being made. The additional time required to determine the actual current employed by using a pointer-stop-ammeter and primary clamp-on transformer or by a calibrated oscilloscope or other means is usually a good investment in maintaining records and in trouble shooting.

3.24 Electrodes. Electrode material generally recommended for the spot welding of the high-nickel alloys are as follows:

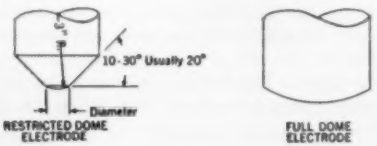
TABLE 3.24

Material	RWMA† Classification	Rockwell Hardness	Conductivity I.A.C.S. %
Copper Alloy.....	Grade A Class 1	68 Rb	80
Copper Alloy.....	Grade A Class 2	75 Rb	70
Molybdenum Alloy.	—	83 Rb	33

† Resistance Welder Manufacturer's Association.

Normally both electrodes are the same composition (have the same conductivity) but occasionally in welding dissimilar thicknesses in the same alloy or in welding dissimilar alloys, it is necessary to employ electrodes with different conductivity. See Table 3.31 for the use of molybdenum-faced electrodes when spot welding dissimilar thicknesses of Inconel.

The recommended shape of electrode is a restricted dome, thus:



The restricted domed electrode is easier to set up than the flat, truncated cone electrode and it allows for slight deflection of the arms. A 3 in. radius has been selected as a good average radius for material up to 1/8 in. thick. The flat-faced electrode or one with a dome of 5 or 8 in. radius is sometimes preferred for heavier material (0.062 to 0.125 in.) because it gives a larger size nugget and correspondingly greater shear strengths with a given machine setting.

The angle of cone is unimportant on the harder materials and may be increased to 30° for visibility. With a soft material like annealed nickel, however, some sticking in the form of mechanical keying will be experienced. A low angle of 10° will help to eliminate this sticking.

Full-domed electrodes such as those employed for welding aluminum should not be used for high-nickel alloys. Hard alloys resist indentation of a full dome, and prevent proper forging, thus tending to promote porosity or cracking. The amount of indentation, and thus area, is dependent on the temper of the sheet. Slight variations in sheet temper will cause inconsistencies in the weld strengths because of inconsistent weld areas.

Spot-welding electrodes may be lightly dressed with fine emery cloth on a rubber-covered paddle or with proper tools to maintain their original shape and finish. Major removal of metal with a hand file should never be permitted. When an electrode needs major repair, it should be removed from the machine and refaced in a lathe.

3.3 Welding Procedure

3.31 Recommended Practices. Table 3.31 shows the recommended machine settings for spot welding various gages and combinations of gages of nickel, Monel and Inconel. The machine settings listed in this table are not the only combinations of variables that will produce satisfactory welds; however, they are thought to be optimum. If other values of pressure, time and current are employed, the net result of nugget diameter and shear strength can be checked against columns H, I and J.

Tabular data of this nature is not yet available for the age-hardenable alloys—Duranickel,* K Monel and Inconel X. In general, they may be welded with about the same machine settings as the solid solution alloys but employing more pressure and somewhat less current to compensate for their greater strength and higher resistance, respectively. The nuggets will be about the same size as in the solid solution alloys but the shear strengths will be higher in the as-welded condition. Subsequent age hardening will increase the shear strength by about 50%.

Some cracking may occur when spot welding age-hardenable alloys if insufficient pressure is employed. When it is not possible to eliminate this cracking by in-

* Reg. U. S. Pat. Off.

creasing the pressure, a long weld time or a pulse of post-weld current somewhat reduced from the magnitude of the welding current will help in eliminating cracking. It has been reported that less cracking has been encountered with machines with low inertia heads and with provision for slope control than with conventional machines and setups.

3.32 Welding Dissimilar Metal Combinations. Nickel and the high-nickel alloys can be spot welded to themselves or to other materials such as mild steel, low-alloy steels, stainless steels, some copper alloys, tungsten, molybdenum but not to aluminum or magnesium alloys. Table 3.32 outlines the recommended procedure for welding some dissimilar metals combinations where the two pieces are 0.063 in. in thickness. Satisfactory spot welds have been made using these procedures on conventional a.-c. machines with low inertia heads and using slope control, and on three-phase, direct-current dry disk rectifier machines.

Little investigational work has been done in developing machine settings for all possible combinations. The number of possible combinations of dissimilar metals in dissimilar thickness combinations is almost limitless. Most applications have been highly specialized and have been solved by the people most interested in the application without extensive reports of the results obtained. The practicability of spot welding dissimilar metals combinations must be judged on the basis of each individual application. The quality of weld obtained might be highly satisfactory for a toy or jewelry but the same weld might not be satisfactory for aircraft use. Before freezing a design which involves spot welding such a combination, it is highly desirable to investigate the feasibility of making such a weld in production. A thorough trial is the only safe procedure.

The following comments are intended as hints to people who must find a procedure to spot weld a dissimilar metals combination.

(*a*) The greatest difficulty can be expected in a combination which, when mixed in the weld nugget, forms an alloy with undesirable characteristics. Monel and steel or stainless and mild steel are two such examples. No difficulty will be experienced if an alloy with desirable characteristics is formed. Any procedure which will minimize the mixing of the two base materials in the nugget will be helpful. High welding currents with short welding times tend to do this. Projection welding will also tend to prevent mixing.

(*b*) When the resistivity of the two materials and their melting point varies widely, a nugget is sometimes formed entirely within the high-resistance material and no joint is made. High-resistance electrodes against the low-resistance material, or small diameter electrodes against the low-resistance material and larger diameter electrodes against the high resistance material, or a combination of both will pull the nugget across the faying surface line.

(*c*) An unconventional braze type weld where the nugget is entirely contained within one material with a braze type adherence to the other material might be useful. Such a weld can occur between Inconel X and Stainless 347 or between Monel and steel. (See Fig. 3.32 (*c*).)

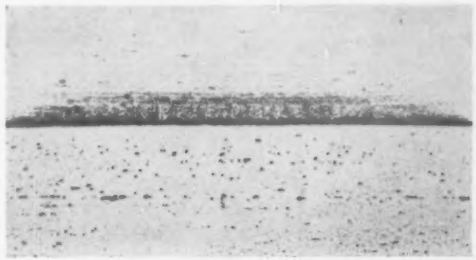


Fig. 3.32 (c) Braze type weld (Monel to steel). 18 ×

(*d*) Test the resulting weld for impact strength or fatigue strength if these qualities are important to the product. The welds formed may be brittle and may not exhibit this trait in a simple test. (See Par. 3.5.)

3.4 Defects

Any good manufacturing process requires a good inspection and control system to judge the quality and consistency of results and to take appropriate action when quality falls below a preset standard. Spot welding is a good production tool which will yield consistency of result in the same order of magnitude as results from lathes, screw machines or punch presses. Unfortunately, the means of testing spot welds are not as simple as the use of micrometer caliper, and the results noted are not as easy to interpret and to correct for.

Under certain conditions, the following defects can be found in spot welds.

3.410 Surface burning or spitting.
3.411 Expulsion.
3.412 Excessive indentation.
3.413 Distortion.
3.414 Porosity.
3.415 Cracking.
3.416 Intergranular melting (coring).
3.417 Misplaced nugget.
3.418 Misshaped nugget.
3.419 Low Strength.

These defects are no different from those found in the spot welding of other alloys. Because the high-nickel alloys are used in places where their special properties will show economic advantage, and generally applied in the thinnest sections possible, the effect of these defects may be more pronounced.

3.410. Surface burning can be caused by:

1. Dirty material or fouled electrodes.
2. Too much penetration of nugget.
3. Improper machine sequence.

TABLE 3.31

Recommended Conditions for Spot Welding Annealed Nickel Sheet

ASTM (B-162-49T)

A Thickness inches	B Electrode Diameter Top	B Electrode Diameter Bottom	C Electrode Force lbs.	D Weld Time cycles	E Weld Current amps.	F Minimum Contact Overlap in.	G Minimum Weld Spacing in.	H Diameter Fused Zone in.	I Average Shear Strength psi.	J Minimum Shear Strength psi.
0.005 to—										
0.005	3/32	3/32	100	3	7,100	1/4	3/8	0.10	40	30
0.010	3/32	3/32	100	3	7,400	1/4	7/16	0.10	45	35
0.015	3/32	3/32	110	3	7,500	1/4	7/16	0.10	48	40
0.021	3/32	3/32	110	3	7,800	1/4	1/2	0.10	58	45
0.031	3/32	3/16	110	3	8,000	1/4	1/2	0.10	63	50
0.063	3/32	3/16	115	3	8,100	1/4	5/8	0.10	65	50
0.093	3/32	3/16	115	3	8,150	1/4	5/8	0.10	65	50
0.125	3/32	3/16	115	3	8,200	1/4	5/8	0.10	68	55
0.010 to—										
0.010	3/16	3/16	130	3	11,800	1/4	3/8	0.12	170	135
0.015	3/32	3/16	130	3	11,900	1/4	3/8	0.12	180	145
0.021	3/32	3/16	130	3	12,000	1/4	7/16	0.12	190	150
0.031	3/32	3/16	130	3	12,200	1/4	7/16	0.12	202	160
0.063	3/32	3/16	140	3	12,300	1/4	1/2	0.12	234	185
0.094	3/32	3/16	140	3	12,300	1/4	5/8	0.12	240	190
0.125	3/32	3/16	150	3	12,500	1/4	5/8	0.12	260	210
0.015 to—										
0.015	3/16	3/16	250	3	12,300	1/4	7/16	0.12	225	180
0.021	3/16	3/16	250	3	12,500	1/4	1/2	0.13	310	250
0.031	3/16	3/16	250	3	12,600	1/4	1/2	0.13	350	280
0.063	3/16	1/4	260	3	12,800	1/4	9/16	0.13	372	300
0.094	3/16	5/8	260	3	13,000	1/4	5/8	0.13	380	305
0.125	3/16	5/8	260	3	13,100	1/4	5/8	0.13	390	310
0.021 to—										
0.021	3/32	5/32	370	4	7,800	5/16	9/16	0.12	440	350
0.031	3/32	5/32	370	4	8,200	5/16	5/8	0.12	462	370
0.063	3/32	5/32	370	4	8,600	5/16	5/8	0.12	496	395
0.094	3/32	5/8	380	4	8,800	5/16	11/16	0.12	535	430
0.125	3/32	5/8	380	4	9,000	5/16	3/4	0.13	566	450
0.031 to—										
0.031	5/16	3/16	900	4	15,400	3/8	7/8	0.18	950	760
0.063	5/16	3/16	900	4	15,200	3/8	7/8	0.17	866	770
0.094	5/16	3/16	900	6	13,500	3/8	1	0.18	1050	840
0.125	5/16	5/8	980	6	14,200	3/8	1	0.18	1160	930
0.063 to—										
0.063	1/4	1/4	1720	6	21,600	5/8	1 1/2	0.25	3000	2400
0.094	1/4	1/4	1800	8	20,000	5/8	1 5/8	0.25	3188	2550
0.125	1/4	1/4	1800	10	21,000	5/8	1 3/4	0.25	3316	2650
0.094 to—										
0.094	5/16	5/16	2300	12	26,400	3/4	1 7/8	0.31	4500	3600
0.125	5/16	5/16	2300	20	25,400	3/4	2	0.31	4720	3780
0.125 to—										
0.125	3/8	3/8	3300	20	31,000	7/8	2 1/4	0.37	7000	5600

NOTES:

1. Material should be free from scale, oxides, paint, grease and oil.
2. Electrode shape may be flat rather than domed, in which case the shear strengths and nugget diameters will be higher and larger than shown in the table.
3. Electrode Materials,

	Class 1 or	*Class 2*
Minimum conductivity	80% Cu	75% Cu
Minimum hardness	68 Rb	75 Rb

4. Minimum weld spacing is that spacing for two pieces for which no special precautions need be taken to compensate for shunted current effect of adjacent welds. For three pieces increase spacing 30 percent.

TABLE 3.31 (Continued)

Recommended Conditions for Spot Welding Annealed Monel Sheet

ASTM (B-127-49T)

A Thickness inches	B Electrode Diameter		C Electrode Force lbs.	D Weld Time cycles	E Weld Current amps.	F Minimum Contact Overlap in.	G Minimum Weld Spacing in.	H Diameter Fused Zone in.	I Average Shear Strength psi.	J Minimum Shear Strength psi.
	Top	Bottom								
0.005 to—										
0.005	5/32	5/32	220	2	5,000	1/4	1/4	0.10	70	55
0.010	5/32	5/32	220	2	6,100	1/4	1/4	0.10	76	60
0.015	5/32	5/32	220	2	7,000	1/4	5/16	0.10	94	75
0.021	5/32	1/4	220	3	7,200	1/4	3/8	0.11	108	85
0.031	5/32	1/4	250	4	7,400	1/4	3/8	0.11	118	95
0.063	5/32	5/16	250	4	8,000	1/4	7/16	0.11	112	90
0.094	5/32	5/16	250	4	8,600	1/4	1/2	0.11	110	90
0.125	5/32	5/16	250	4	8,700	1/4	1/2	0.11	108	85
0.010 to—										
0.010	5/32	5/32	270	2	7,200	1/4	1/4	0.12	180	145
0.015	5/32	5/32	280	2	8,600	1/4	5/16	0.12	196	155
0.021	5/32	5/32	280	3	8,200	1/4	5/16	0.13	214	170
0.031	5/32	5/32	300	4	8,800	1/4	3/8	0.13	236	190
0.063	5/32	5/16	300	4	9,200	1/4	7/16	0.13	238	190
0.094	5/32	5/16	325	4	9,900	1/4	1/2	0.14	268	210
0.125	5/32	5/16	325	4	9,900	1/4	1/2	0.14	276	220
0.015 to—										
0.015	3/16	3/16	300	2	8,600	1/4	5/16	0.13	310	250
0.021	3/16	3/16	300	6	8,200	1/4	3/8	0.13	368	295
0.031	3/16	3/16	325	6	9,300	1/4	3/8	0.13	376	300
0.063	3/16	5/16	325	6	9,400	1/4	7/16	0.14	436	350
0.093	3/16	5/16	325	8	9,500	1/4	1/2	0.14	448	360
0.125	3/16	5/16	325	8	9,500	1/4	1/2	0.14	456	365
0.021 to—										
0.021	3/16	3/16	300	12	6,200	3/16	7/16	0.13	560	450
0.031	3/16	3/16	325	12	6,800	3/16	7/16	0.13	578	460
0.063	3/16	3/16	325	12	7,200	3/16	1/2	0.14	624	500
0.093	3/16	5/16	325	12	7,700	3/16	9/16	0.14	660	530
0.125	3/16	5/16	325	12	8,200	3/16	9/16	0.14	692	550
0.031 to—										
0.031	3/16	3/16	700	12	10,500	3/16	5/16	0.17	1056	845
0.063	3/16	1/4	750	12	11,200	1/2	11/16	0.18	1138	910
0.094	3/16	5/16	775	12	11,400	1/2	3/4	0.19	1296	1035
0.125	3/16	5/16	775	12	11,800	1/2	3/4	0.19	1348	1075
0.063 to—										
0.063	5/16	5/16	2700	12	15,300	5/8	1 1/8	0.31	2584	2060
0.093	5/16	5/16	2700	12	15,900	5/8	1 3/16	0.31	2734	2180
0.125	5/16	5/16	2700	12	16,200	5/8	1 1/4	0.32	2944	2360
0.093 to—										
0.093	3/8	3/8	2760	20	22,600	3/4	1 1/4	0.37	4860	3880
0.125	3/8	3/8	2760	20	25,000	3/4	1 1/4	0.38	5480	4390
0.125 to—										
0.125	1/2	1/2	5000	30	30,000	7/8	1 5/8	0.47	7300	5850

NOTES:

1. **Material should be free from scale, oxides, paint, grease and oil.**
2. **Electrode shape may be flat rather than domed, in which case the shear strengths and nugget diameters will be higher and larger than shown in the table.**
3. **Electrode Materials,**

	Class 1 or	*Class 2*
Minimum conductivity	80% Cu	75% Cu
Minimum hardness	68 Rb	75 Rb

4. **Minimum weld spacing is that spacing for two pieces for which no special precautions need be taken to compensate for shunted current effect of adjacent welds. For three pieces increase spacing 30 percent.**

TABLE 3.31 (Concluded)

Recommended Conditions for Spot Welding Annealed Inconel Sheet

ASTM (B-168-49T)

A Thickness inches	B Electrode Diameter		C Electrode Force lbs.	D Weld Time cycles	E Weld Current amps.	F Minimum Contact Overlap in.	G Minimum Weld Spacing in.	H Diameter Fused Zone in.	I Average Shear Strength psi.	J Minimum Shear Strength psi.
	Top	Bottom								
0.005 to—										
0.005	1/32	1/32	300	2	7,000	1/4	1/4	0.11	90	70
0.010	1/32	3/16	300	4	5,300	1/4	1/4	0.12	125	100
0.015	1/32*	3/16	300	4	5,500	1/4	1/4	0.12	135	105
0.021	1/32*	3/16	300	6	4,800	1/4	5/16	0.13	140	110
0.031	1/32*	3/16	325	6	5,400	1/4	5/16	0.13	150	120
0.062	1/32*	5/8	325	6	5,600	1/4	3/8	0.15	172	135
0.094	1/32*	5/8	325	6	5,800	1/4	3/8	0.16	184	145
0.125	1/32*	5/8	325	6	5,600	1/4	3/8	0.15	160	130
0.010 to—										
0.010	3/16	3/16	320	4	7,500	1/4	1/4	0.12	220	175
0.015	1/32*	3/16	320	4	5,500	1/4	1/4	0.13	270	215
0.021	1/32*	3/16	320	6	5,100	1/4	9/32	0.13	270	215
0.031	1/32*	3/16	350	6	5,600	1/4	9/32	0.14	360	290
0.063	1/32*	3/16	400	6	5,500	1/4	5/16	0.14	395	315
0.094	1/32*	5/8	400	6	5,800	1/4	3/8	0.15	440	350
0.125	1/32*	5/8	400	6	4,600	1/4	3/8	0.14	365	370
0.015 to—										
0.015	3/16	3/16	360	6	7,600	1/4	1/4	0.12	370	295
0.021	3/16	3/16	360	6	5,400	1/4	1/4	0.12	360	290
0.031	1/32*	3/16	400	8	4,600	1/4	9/32	0.13	460	370
0.063	1/32*	3/16	400	8	4,700	1/4	5/16	0.13	550	440
0.094	3/16*	5/8	400	10	4,700	1/4	11/32	0.16	670	535
0.125	3/16	5/8	400	12	4,600	1/4	3/8	0.16	700	560
0.021 to—										
0.021	1/32	1/32	300	12	4,000	5/16	7/16	0.12	680	545
0.031	1/32	3/16	350	12	4,100	5/16	7/16	0.12	670	535
0.063	3/16*	3/16	400	12	5,300	5/16	13/32	0.12	775	580
0.094	3/16*	5/8	500	12	5,900	5/16	1/2	0.15	828	670
0.125	3/16*	5/8	550	12	6,300	5/16	1/2	0.15	860	690
0.031 to—										
0.031	3/16	3/16	700	12	6,700	3/8	9/16	0.18	1150	920
0.063	3/16	3/16	700	12	7,100	3/8	3/8	0.18	1210	965
0.094	1/4*	5/8	700	12	8,300	3/8	11/16	0.20	1565	1250
0.125	1/4*	5/8	750	12	8,500	3/8	3/4	0.20	1510	1210
0.063 to—										
0.063	3/16	3/16	2070	12	12,000	5/8	1 3/16	0.31	3450	2750
0.093	3/16	5/8	2450	16	12,000	5/8	1 3/16	0.31	3420	2750
0.125	3/16	5/8	2600	20	12,000	5/8	1 1/4	0.32	3530	3820
0.093 to—										
0.093	3/8	3/8	3870	20	15,000	3/4	1 3/16	0.37	5500	4400
0.125	7/16	7/16	5100	30	20,000	3/4	1 1/4	0.40	5880	4700
0.125 to—										
0.125	7/16	7/16	5270	30	20,100	7/8	1 5/16	0.44	8000	6400

* Indicates molybdenum tipped electrode.

NOTES:

1. Material should be free from scale, oxides, paint, grease and oil.
2. Electrode shape may be flat rather than domed, in which case the shear strengths and nugget diameters will be higher and larger than shown in the table.
3. Electrode Materials, *Class 1* or *Class 2* or *Molybdenum faced*

	Class 1	Class 2	Molybdenum faced
Minimum conductivity.....	80% Cu	75% Cu	33% Cu
Minimum hardness	68 Rb	75 Rb	83 Rb

4. Minimum weld spacing is that spacing for two pieces for which no special precautions need be taken to compensate for shunted current effect of adjacent welds. For three pieces increase spacing 30 percent.

TABLE 3.32

Recommended Conditions for Spot Welding Some Dissimilar Metals Combinations

Material Combination	A Thickness in.	B Electrode[3] Size in.	C Electrode Force lbs.	D Weld Time Cycles	E Weld Current amps.	F Min. Overlap in.	G Min. Weld Spacing in.	H Diameter Fused Zone in.	I Shear Strength lbs.
Nickel—mild steel	0.063	5/16	1300	10	16,200	5/8	1 1/4"	0.25	2200
Nickel—low alloy steel (8630)	0.063	5/16	1500	10	14,500	5/8	1 1/4"	0.25	2350
Nickel—stainless steel[1]	0.063	5/16	1800	12	16,000	5/8	1 1/4"	0.25	2700
Nickel—Monel	0.063	5/16	2000	12	20,000	5/8	1 1/4"	0.28	2900
Nickel—Inconel	0.063	5/16[2]	2500	12	15,500	5/8	1 1/4"	0.26	2750
Monel—mild steel	0.063	5/16	1600	14	17,500	5/8	1 1/4"	0.25	2300
Monel—low alloy steel (8630)	0.063	5/16	1600	14	16,800	5/8	1 1/4"	0.25	2450
Monel—stainless steel[1]	0.063	5/16	1800	14	16,000	5/8	1 1/4"	0.25	2800
Monel—Inconel	0.063	5/16	2300	14	15,500	5/8	1 1/4"	0.25	3000
Inconel—mild steel	0.063	5/16	1600	14	17,000	5/8	1 1/4"	0.23	2200
Inconel—low alloy steel (8630)	0.063	5/16	1600	14	16,000	5/8	1 1/4"	0.25	2300
Inconel—stainless steel[1]	0.063	5/16	2500	16	14,000	5/8	1 1/4"	0.28	2950
Stainless[1]—mild steel	0.063	5/16	1600	14	18,000	5/8	1 1/4"	0.25	2170
Stainless[1]—low alloy steel (8630)	0.063	5/16	1600	14	17,500	5/8	1 1/4"	0.26	2400

[1] 18-8 Stainless.
[2] Class III electrode against nickel sheet.
[3] Electrodes RWMA Class II 3" Radius of Dome.

Usually simple visual inspection will be sufficient to observe surface burning. To eliminate, clean the material (see Par. 2.2) or replace the electrode, or reduce the current, or see that the current is turned off before the machine pressure is released. Slope control in the weld timer has been accredited with reducing surface burning.

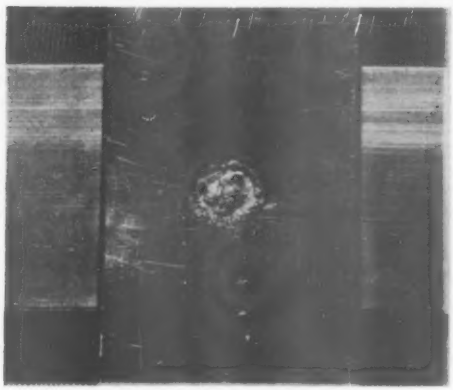


Fig. 3.410 Spitting or surface burning. 2 ×

3.411. Expulsion can be caused by:

1. Welding too near an edge.
2. Welding on dirty material.
3. Welding with too little pressure or too much current.
4. Using part of the machine pressure to form the parts.

Simple visual examination, particularly at the time of welding, will disclose expulsion. Radiographic examination is the best method of noting expulsion although it can be seen in tensile shear tests and in other destructive tests. To eliminate, use a wider flange and be careful of fit of parts, clean the material, decrease the current or increase the pressure. Slope control has also been helpful in eliminating expulsion in difficult cases where the usual corrective procedure cannot be employed.

Fig. 3.411 Section of a weld from which metal has been expelled. 50 ×

3.412. Excessive indentation can be caused by:

1. Too long a welding time.
2. Too much machine pressure.
3. The result of expulsion.

Visual examination or measurement with a micrometer depth gage is sufficient to detect excessive indentation. A maximum allowable indentation of 5% of the total thickness being welded is a common specification requirement. Zero indentation is extremely difficult to achieve since some of the indentation is caused by shrinkage of the weld nugget. Indentation can be minimized by decreasing the welding time, decreasing the welding pressure (but only if this pressure is very excessive), eliminating expulsion, using a flat electrode

on the most important side (the opposite side will have a correspondingly deeper indentation) or by resorting to projection welding.

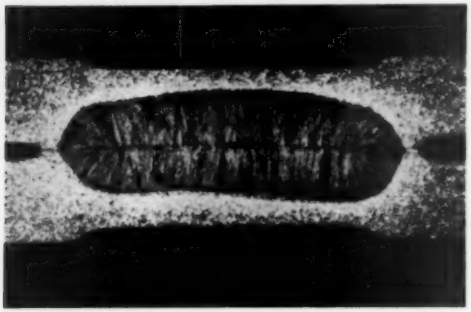


Fig. 3.412–3.413 Excessive indentation and distortion in a spot weld. 12 ×

3.413. Distortion can be caused by:

1. Excessive indentation.
2. Expulsion.
3. Misalignment of electrodes or excessive welder arm deflection.

Distortion can be measured by sectioning the pieces and measuring the width of gap between sheets. Usually 10% of the thinner piece is allowable. To minimize distortion, see 3.411 and 3.412 above.

3.414. Porosity can be caused by:

1. Expulsion.
2. Dirty material.
3. Insufficient pressure.
4. A combination of materials which is prone to cause porosity.

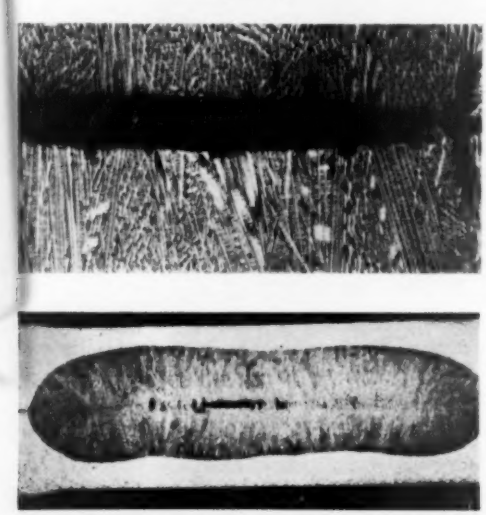


Fig. 3.414 Porosity in a spot weld. 100 × and 10 ×

Porosity will be found in a certain percentage of all spot welding. Usually this percentage is around 5 to 10% of the welds. If the cavity is small, round and nearly central to the weld, there is no evidence that such porosity will adversely affect the mechanical properties of the weld. Only when the porosity is large with respect to the weld, or when it has sharp, irregular outlines will it tend to affect the mechanical properties of the weld. Radiographs disclose all porosity. Sectioning and etching will also disclose porosity but only if the cavity is included in the section. To minimize porosity, use clean material and avoid expulsion (see 3.411 above). Unit pressure must be high. Sometimes a combination of dissimilar metals will be prone to give porosity. Usually it is possible to find a machine setting which will minimize this condition (see Par. 3.32).

Fig. 3.415 Cracking in a seam weld. 25 ×

3.415. Cracking can be caused by:

1. Expulsion.
2. Insufficient pressure.
3. A combination of metals tending to be hot short.

Cracking in spot welds usually is contained entirely within the weld. Radiographic examination will disclose a "crow's foot" in the center of the weld. Sectioning and etching will show one or more cracks normal to the surface. (See Fig. 3.415.) Usually a magnification of about 100 × is required to identify a crack positively. A crack in a spot weld may tend to propagate and lead to ultimate failure of the structure. Cracking can be eliminated by eliminating porosity, using high unit pressures to forge the weld during nugget solidification and in exceptional cases where sufficient pressure cannot be employed, or where the metal combination has an unusual cracking tendency by using pulsation welding, or by following the weld period with an additional pulse of power of lower current to spread the heat over a larger area in order that shrinkage stresses will not be so greatly localized.

3.416. The high-nickel alloys exhibit a phenomenon that has been called "coring." Examination of Fig. 3.416 (*a*) will show small defects at the corners which at low magnification appear to be cracks. If these areas are examined at higher magnification as in Fig. 3.416 (*b*), it will be seen that dendritic material completely fills these "cracks." It is thought that melting along the grain boundaries takes place at critical pressure

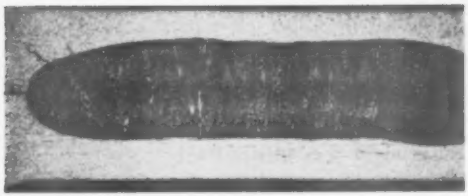
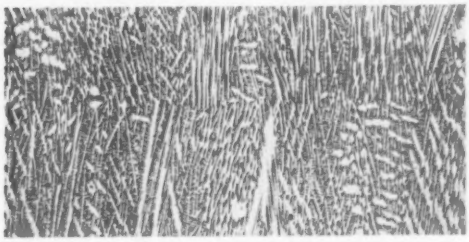


Fig. 3.416 (a) Typical weld made in 0.062 in. annealed Monel sheet at recommended welding conditions. 8.5 ×



Center of weld shown above. 70 ×

areas where there is a change in stress due to the shape of electrode. So far, there has been no evidence to show that this coring is detrimental to the mechanical properties of the weld. Cracking in the high-nickel alloys should be examined at high magnification to determine whether they are true cracks or only coring.

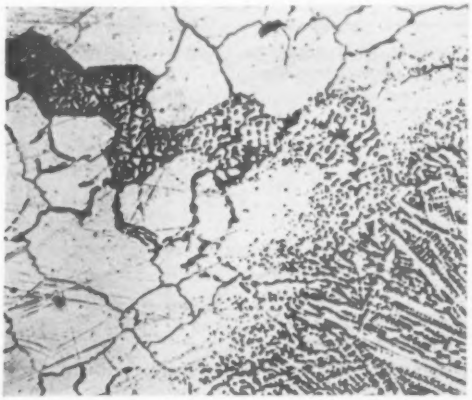


Fig. 3.416 (b) Section of a Monel weld showing typical structure appearing at the edges of the weld. 300 ×

3.417. A misplaced nugget may be caused when:

1. Welding dissimilar thicknesses of the same metal.
2. Welding dissimilar metals.
3. Combinations of 1 and 2.
4. Uneven sizes of electrodes or electrodes of different materials.

See Section 3.32 for a discussion of the methods used to center the nugget on the faying surface.

Fig. 3.417 Misplaced nugget in Monel-Nickel spot weld showing nugget located entirely in Monel. 18 ×

3.418. Misshaped nuggets can be caused by the following:

1. Mis-shaped electrodes.
2. Misaligned electrodes.
3. Too much tip radius.

Radiographing will disclose the presence of misshaped welds in the plane of the sheets. Sectioning and etching will disclose the presence of misshaped welds in a plane normal to that of the sheet. To eliminate misshaped nuggets, use only electrodes that have been machine cut. Do not dress electrodes with a file (see Section 3.24). Be sure the electrodes are properly aligned, and be sure that too small a radius is not used.

Fig. 3.418 Misshaped nugget caused by misshaped electrodes. 18 ×

3.419. Low strength in a spot weld can be caused by:

1. Too small a weld for the sheet thickness.
2. No fusion, but only a "stuck" weld.
3. Defects such as expulsion, cracking, or major indentation.

A simple tension shear test of a spot weld will fail by shearing through the nugget if the nugget is too small or by tearing the sheet in a button type failure if the nugget is above a certain minimum size. For the high-nickel alloys, the following nugget size will insure failure by tearing the sheet.

TABLE 3.419

Material	Ratio $\frac{\text{Weld Diameter}}{\text{Sheet Thickness}}$	
	Annealed	½ Hard
Nickel	3	3½
Monel	3½	4
Inconel	4	4½

Of course, if no nugget is formed and the weld is merely a "stuck" weld (pressure weld), failure will always occur through the weld. Unfortunately, the high shear strength of stuck welds in high-nickel alloys gives the erroneous impression that these welds have good mechanical properties. Such is not the case. Stuck welds are poor in fatigue and impact loading, and have very low ductility.

3.5 Tests for Welds

The above discussion of defects in welds has mentioned several tests of spot welds which are used to discover defects and to evaluate the welds. The following tests for welds are used on the welding floor and in the laboratory.

3.510 Visual inspection	3.516 Cross-tension test
3.511 Radiographic test	3.517 U-tension test
3.512 Peel test	3.518 Shear-impact test
3.513 Twist test	3.519 Drop-impact test
3.514 Tension shear test	3.520 Fatigue test
3.515 Macroetch test	3.521 Hardness test

3.510. Visual inspection will disclose defects on the surface such as surface burning, indentation and expulsion near an edge, but it is never sufficient to fully evaluate the quality of a weld.

3.511. Radiography is the only nondestructive test for welds, aside from visual inspection. It is the most dependable way of determining the presence of such defects as porosity, cracking, expulsion and misshaped nuggets. In the high-nickel alloys it is a valuable tool, but it will not give indications of strength.

3.512. The peel test is a common test used in many shops where spot welding is done. This test consists of prying the sheets apart and peeling one sheet back over the other in "can opener" fashion. If failure occurs by shearing through the nugget, the weld is considered unsatisfactory. If failure occurs by tearing a button from the sheet, the weld is considered satisfactory. The peel test is not considered satisfactory for the high-nickel alloys. The very low-strength welds will fail by shear through the nugget, but some "stuck" welds will pull buttons.

3.513. The twist test consists of twisting the two sheets apart about an axis perpendicular to the sheet and at the center of the weld. The torque required and the angle of twist attained before final separation are approximate measures of the strength and ductility of the weld. This is a good shop test to evaluate approximately what results can be expected in the tensile shear test. No special equipment is required. It is not strictly quantitative although some attempt has been made to make this test more quantitative. Stuck welds will shear free with a very small angle of twist. Good welds will shear after 90–180° twist depending somewhat on inherent ductility of material in the temper tested.

3.514. The tension shear test is the most common strength test used in evaluating spot welds. It gives a good indication of the strength of the weld but does not indicate how the weld will behave under impact or fatigue, and does not indicate the order of ductility of the weld. This test is useful for shop setup and control work and also for laboratory investigations.

3.515. The macroetch test is very simple and extremely useful in evaluating the quality of weld. The procedure is to:

1. Scribe a line through the center of the weld to be examined.

2. Cut to one side of the line with a hacksaw, power saw, cut-off wheel or other means.

3. File to the line, then polish with fine emery cloth. The degree of smoothness required will depend on the amount of magnification used in examining the section. For visual or low magnification of 5–10 ×, a good fine file finish is usually satisfactory. For higher magnification a greater degree of polish is desirable Metallographic techniques for polishing can be used but they are not essential.

4. Etch the surface with a suitable etchant which will remove the burrs and flowed surface and which will disclose the structure of the weld with sufficient contrast for satisfactory visual examination. Sometimes too drastic an etch will produce "defects" which are not there. The degree of etch is somewhat dependent on the power of magnification to be used in inspecting the weld. The following table will suggest suitable etchants for macroscopic examination.

TABLE 3.515
Macro Etchants for Weld Examination

Material	Etchant Number
Nickel	1
Duranickel	1
Monel	1
"K" Monel	1 or 2
Inconel	2 or 3 or 4
Inconel "X"	2 or 3 or 4

Make-up of Formulae

	1	2[2]	3[1]	4[2]
Water				7.5 cc.
Nitric Acid, Conc.	√		¼	3.0 cc.
Hydrochloric Acid			¾	10 cc.
Oxolic Acid, 10 per cent		√		
Ammonium Sulphate $(NH_4)_2(SO_4)$				1.5 grams
Ferric Chloride ($FeCl_3$)				25 grams

1. Warm the parts for faster action.
2. Mix solution as follows:
   a. Dissolve $(NH_4)_2(SO_4)$ in H_2O.
   b. Dissolve powdered $FeCl_3$ in HCl.
   c. Mix (a) and (b) and add HNO_3.
3. Electrolytic.

5. Examine the section for defects and measure the diameter of weld and penetration of weld with a scale.

This entire procedure takes about 5 min. to perform. A friction cut-off wheel and polishing buffs will aid in reducing the effort and time consumed.

3.516 to 3.521. Special tests are frequently required for welds employed in special applications. (See third reference in Bibliography, Section 8.) The tests listed above are generally not used for the usual spot weld evaluations.

3.6 The Need for Tests

The actual tests employed depend upon the importance of the structure being welded and upon the availability of equipment. Obviously, some of the testing equipment is expensive and its use can only be justified if the quality of welding must be maintained at a high level. Conversely, some of the tests require very little expenditure of money for equipment and time. There is no excuse for not employing the visual examination (3.511), the twist test (3.513) and the macroetch test (3.515) as very minimum tests for observing and controlling the quality of welds. When the size of weld is measured by the macroetch test and correlated with tabulated weld sizes such as those shown in Column H, Table 3.31, or in similar test data, the strength of the weld can be estimated with surprising accuracy.

One test of welds at the beginning of production is not sufficient. Periodic inspection of welds is necessary to be certain that the quality of welding is being maintained. Welds should be tested at the beginning and at the end of short production runs. Longer production runs should be tested at least every two hours in addition to the start and finish.

4. PROJECTION WELDING

Since projection welding is a special form of spot welding, many of the foregoing comments on spot weld ing refer with equal force to projection welding. In order to avoid repetition, only those subjects which relate specifically to projection welding will be discussed.

Projection welding has the following advantages:

(*a*) Projections can be put on small areas where spot welding is not possible.

(*b*) More than one weld can be made with one stroke of the machine. The number welded at once is only limited by the pressure and current available from the machine and by current distribution.

(*c*) Long electrode life.

(*d*) Electrode marking can be practically eliminated on one side.

(*e*) Difficult dissimilar metals combinations are commercially possible.

It also has the following disadvantages:

(*a*) All projections should be seated in one blow.

(*b*) A prior operation is necessary to form the projection.

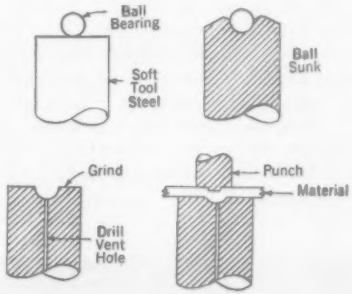
(*c*) Special welding dies are necessary.

On high production welding of small parts or the welding of small parts to large parts, the advantages far outweigh the disadvantages.

4.1 Design Considerations

Projections in sheet material are usually made on a punch press. Most frequently the projections can be included in a blanking or forming operation by slightly altering the dies. The height of a projection is governed by *the thickness of the piece to which the part bearing the projection is to be welded.* Usually this height will be around 80% of the thickness for thin materials and around 50% for thicker materials. Where a choice exists, the projection should be placed in the heavier piece or in the piece having the higher conductivity. The shape of the projection should start with an initial point or line contact. The size of a projection should bear a certain relationship with the size of the weld desired. Usually the weld is larger than the projection size so a projection size of 3 or 4 times the sheet thickness is common.

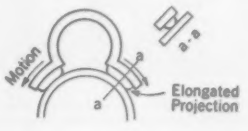
One convenient way of making a projection die is to select a ball bearing of the desired size and sink it about half-way into a soft tool steel block. Surface grind the face to get the correct projection height. Drill a small hole through the block to vent air and oil during the punching operation. Harden the die. The punch is a truncated cone of the same volume as the impression in the die.



It is generally more economical to use two or more round projections rather than one elongated projection. Elongated projections should only be used when there is relative movement between parts during welding and then the projections should be elongated in the direction of motion.

Projections may also be machine cut on bar stock or may be formed in a heading operation.

Hardware in the form of nuts, bolts, bosses, angles,



etc., are available commercially* with projections for welding.

4.2 *Equipment*

Projection welding of small parts can be done with flat electrodes in the conventional spot-welding machine. Larger pieces will require dies too cumbersome for such attachment. These larger dies are attached by T bolts to the platens of a projection welding machine or a combination spot and projection welding machine.

4.21 Dies and Fixtures. Special projection welding dies are required for each job. The current-carrying portions of these dies may be made of copper for short runs or hard copper alloys for longer runs, or for very long runs the tungsten-copper alloys. The R.W.M.A. tables may be referred to for the best recommendations. The lower die usually contains some locating device so that the parts can be placed in the correct relative position prior to machine operation. The locating devices are much like those employed in punch press operation with the exception that the locating pins must be insulated so they will not carry current.

4.3 *Welding Procedure*

The welding machine settings used for projection welding are seldom recorded and published for general use. Usually the shape of projections, size of parts and location of projection on special parts are so specialized that little general information can be gleaned from machine settings used on specific jobs. On the other hand, it is not difficult to obtain a machine setting once the parts are made. The welds obtained by trial can be inspected by the methods described in Section 3.4.

* Ohio Nut & Bolt Co., Berea, Ohio; Midland Steel Products Co., Midland, Mich.

Fig. 4.31 Section of a cross-wire weld showing pronounced oxide layer at weld interface and relative grain size. 100 ×

4.31 Cross Wire Welding. A special form of projection welding is self-explanatory in the name cross-wire welding. A natural projection occurs due to the shape of the parts. This process is used in the fabrication of screens of nickel and nickel alloy wires and in the manufacture of pickling equipment. Flat electrodes are recommended. Material cleanliness is imperative if consistent strengths and corrosion life are to be maintained. Figure 4.31 shows a photomicrograph of a cross-wire weld illustrating a pronounced oxide layer at the weld interface which occurred because the material was not clean. Table 4.31 gives the recommended welding condition for various sizes of wire in nickel, Monel and Inconel.

TABLE 4.31
Recommended Conditions for Cross Wire Welding

Wire Diam., In.	Electrode Pressure, Lb.	Firing Time Cycles	Current, Amp.
	NICKEL		
1/16–1/16	90	2	2000
1/8–1/8	180	3	4500
5/16–5/16	360	6	7000
1/16–1/8	90	2	2200
1/16–5/16	90	2	2400
1/8–5/16	180	6	5000
	MONEL		
1/16–1/16	100	2	1630
1/8–1/8	200	3	3700
5/16–5/16	400	6	5700
1/16–1/8	100	2	1790
1/16–5/16	100	2	1950
1/8–5/16	200	3	4050
	INCONEL		
1/16–1/16	125	2	1050
1/8–1/8	250	3	2300
5/16–5/16	500	6	3600
1/16–1/8	125	2	1100
1/16–5/16	125	2	1200
1/8–5/16	250	3	2500

4.32 Projection Welding Dissimilar Metals. It is frequently possible to join a dissimilar metals combination successfully by projection welding when such a combination is difficult to do by spot welding. No specific information is available, but it is usually recommended that the projection be placed on the material of the higher conductivity. A trial of the combination should be judged by tests which will disclose the quality of the weld which is most important.

4.4 *Defects*

The defects found in projection welds are generally similar to those found in spot welds. Such defects are discussed in Paragraph 3.4.

An additional defect peculiar to projection welding occurs when insufficient current or time is employed and the projection is not seated home. In a good projection weld the parts should be in tight contact after welding.

4.5 Test Procedure

Test procedures similar to those employed for spot welds should be used to judge the quality of the weld obtained. Tensile tests or twist tests are best performed on the actual assemblies going through production. Because of the infinite variety of shapes run into it is not possible to tabulate data concerning such tests. Neither is it possible to reduce these to pounds per square inch values. Usually a satisfactory control can be obtained by periodic testing and comparison of the results obtained against past performance.

5. SEAM WELDING

Seam welding is a special form of spot welding in which the domed electrodes of the spot welder are replaced with wheels, or one wheel and a platen. As the wheels roll over the work, the current is turned on and off in a regular pattern such as: two cycles on, four cycles off—repeated. A series of spot welds is the result. If the wheel speed and the time cycle have been adjusted so that a series of overlapping spot welds results, the seam will be gas tight. By increasing the spot spacing, a stitch weld is produced. This method of producing evenly spaced spot welds is much faster than similar results obtained on a spot welder.

The high-nickel alloys have been seam welded in thicknesses from 0.002 to 0.125 in. Unfortunately there is a little factual data published at this time. It is not difficult to develop a machine setting for a given application. Many of the foregoing comments on spot welding apply with equal force to seam welding. In order to avoid repetition, only those subjects which refer specifically to seam welding will be discussed.

5.1 Design Considerations

Usually an overlap greater than that required for spot welding is necessary for seam welding. Since most seam welding is guided by hand, a generous overlap is necessary to permit the wheel to be guided in the proper path without rolling off the edge. If it is necessary to have less overlap in the finished article, it is always possible to trim the edge after welding. Where it is necessary to seam weld into a corner or up to an obstruction such as a flange, two alternatives are possible. The wheel may be notched to clear the obstruction or the seam weld may be finished out by spot welding. Usually it is not necessary to build fixtures or jigs for seam welding. It

TABLE 5.3
Recommended Conditions For Seam Welding Monel

SET-UP VARIABLES			WELDING VARIABLES					FUSION ANALYSIS			
Thickness and Gage	Electrode Shape	Electrode Force (Lbs.)	Timing Cycle (Cycles) "On" time	Timing Cycle (Cycles) "Off" time	Weld Spacing (welds per in.)	Wheel Speed (in. per min.)	Welding Current (Amps.)	Width of Fused Zone (in.)	Weld Overlap	Weld Penetration	
0.062"—16	d = 3/8" R = 6"	2500	8	12	9	20	19,000	0.17	10%	35%	Optimum
		2400-2600	6-10	8-15	7-11	—	16,000-21,000	0.0-0.25	0-15%	0-40%	Permissible range
0.031"—22	d = 3/16" R = 6"	700	4	12	12	19	10,000	0.15	20%	40%	Optimum
		600-800	3-6	8-15	10-14	—	8,500-11,000	0.0-0.18	0-25%	0-45%	Permissible range
Electrodes Unburnished 0.021"—25	d = 3/16" R = 6"	600	3	12	11	22	9,500	0.15	10%	35%	Optimum
		500-700	2-4	8-15	10-12	—	8,000-10,000	0.0-0.18	0-15%	0-40%	Permissible Range
Electrodes Burnished 0.021"—25	d = 3/16" R = 6"	500	2	6	12	38	8,700	0.15	20%	40%	Optimum
		400-600	1-3	4-8	10-14	—	7,200-8,900	0.0-0.18	0-25%	0-50%	Permissible range
Electrodes Burnished 0.015"—29	d = 5/32" R = 6"	300	1	3	12	75	7,600	0.10	15%	35%	Optimum
		250-350	½-1½	2-4	11-13	—	6,800-7,800	0.0-0.11	0-20%	0-40%	Permissible range
Electrodes Burnished 0.010"—32	d = 5/32" R = 3"	200	1	3	12	75	5,300	0.09	15%	30%	Optimum
		150-250	½-1½	2-4	11-13	—	4,800-5,300	0.0-0.10	0-20%	0-35%	Permissible range

is simpler to hold the pieces in correct relation to each other and spot weld them together in an operation prior to the seam welding operation rather than to depend on jigs to hold the proper relationship. Sometimes the spot welding can be done on the seam welding machine, although this is not particularly good practice.

The strength of a properly made seam weld is always stronger than the base materials. If a tension test or a pressure test of a seam weld is carried to failure, the material should fail by tearing outside the weld. Because of this fact, strengths of seam welds are not tabulated as they are for spot welds.

5.2 Equipment Considerations

Seam-welding equipment for welding the high-nickel alloys must be strong and rigid enough to exert the force needed for welding. In addition, the current capacity of the machine must be large enough to produce a proper weld in a short time. The current requirements for Inconel will be similar to those for stainless steels, but more current will be required for Monel and nickel since these alloys have lower resistance. (See Table 2.1.)

Cleanliness as discussed in Section 2.2 is vitally important to seam welding.

Electronic timers for interrupting the current are strongly recommended over magnetic contactors.

5.3 Welding Procedure

Recommended practices for Monel are given in Table 5.3. More data are being developed at this time and will be published as soon as available.

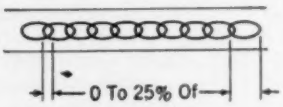
In general, the following principles will apply:

5.31. The welding pressure must be high in order to forge the solidifying nugget and prevent cracking and porosity. The upper limit of pressure is indicated by major distortion and wheel mushrooming. The reasoning for seam welding is similar to that for spot welding discussed in Section 3.21.

5.32. The weld should be made in as short a time as possible considering the current demand of the machine and the desirability of avoiding expulsion. If the "on" time is short, the electrode wheel does not roll off the spot before solidification takes place. Long "on" times will allow the wheel to roll off the weld during nugget solidification. The resulting weld may have porosity and cracking. If the "on" time is too short for the thickness of metal being welded, an extremely high current is required. Such a high current frequently causes surface flashing, tendency toward expulsion, wheel mushrooming and a narrow range of current where welds can be consistently made. Therefore, there is a practical limit below which the time cannot be shortened.

5.33. The weld "off" time should be at least twice the "on" time. If the "off" time is too short, or if the wheel speed is too slow, there will be a tendency to remelt a major portion of the weld already made by shunting a large portion of the welding current through this weld. Remelting without the benefit of pressure will lead to cracking and porosity.

5.34. Wheel speed should be adjusted with suitable current to produce welds which overlap between 0 to 25%.



Surrounding each spot is an area where no melting has taken place but where recrystallization has caused a bond to occur. Such areas have been called pressure-weld areas. It is possible to have the spots spaced with a 25% gap between welds and still have a pressure-tight seam. This practice is not recommended, however, since the quality of pressure welds is poor and inconsistencies are common. (See Fig. 5.33.)

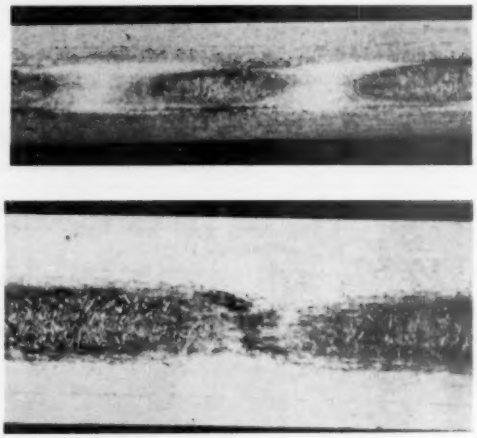


Fig. 5.33 (2 figures) Pressure weld area surrounding seam-weld nugget. 12 × and 20 ×

The wheel speed may be stated in terms of inches per minute or in terms of spots per inch. Conversion may be made as follows:

$$\text{In./min.} = \frac{3600^*}{(\text{"On" time} + \text{"off" time})(\text{No. of spots per in.})}$$

$$\text{Spots/in.} = \frac{3600^*}{(\text{"On" time} + \text{"off" time})(\text{Speed in in. per min.})}$$

* This is based on 60-cycle current. Use 3000 for 50-cycle current and 1500 for 25-cycle current.

Example: If the welding cycle is 2 on and 4 off and there are 6 spots per inch with 60-cycle current what is the rate of welding?

$$\frac{3600}{(2+4)(6)} = 100 \text{ in. per min.}$$

If the seam welder is used to produce a series of welds that are widely spaced (stitch welding) the "off" time may be extended considerably such as 2 "on" and 12

"off." Such a weld will not be gas tight but will be a strong mechanical bond.

5.35. Seam welding wheels may be made of R.W.-M.A. Grade A Class 1 or Class 2 alloys. Wheels are normally flat or radius faced and smooth. It has been found that the burnishing of seam-welder wheels prior to their use is very helpful in preventing sticking, particularly in thin gages. It will be noted that the three thinner gages of Monel in Table 5.3 should be welded with burnished wheels. Burnishing can be accomplished by rolling a small diameter formed roll against the welding surface under high pressure. This operation can be done in the lathe used for facing the wheel. A special tool is used which is similar to a knurling tool but smooth. The serrations on the surface of a knurl drive mechanism are objectionable for the nickel alloys. They not only produce a weld with poor appearance but they also contribute to porosity and cracking difficulties.

5.36. The current is normally the last variable to be fixed. After selecting the wheels, the time cycle and the spot spacing, the current is adjusted to a point just below that at which expulsion takes place. At this current setting a series of overlapping spots should result. If the spots are not large enough to become overlapping, without expulsion occuring, the variables previously selected must be changed and a new current selected until satisfactory welds result.

The only authoritative data available at the present time is shown in Table 5.3.

5.37 Welding Dissimilar Metals Combinations. The comments in Section 3.32 will apply also to seam welding. In one particular instance investigated where 0.050-in. Monel was seam welded to 0.062-in. mild steel, the following machine settings were used:

Pressure—2400 lb.
Time—3 cycles on, 12 cycles off.
Speed—7 spots per inch or 34 in. per minute.
Current—24,000–27,000 amp.
Wheels—R.W.M.A. Grade A, Class 2.
$^{5}/_{16}$-in. flat face against Monel.
$^{1}/_{4}$-in. flat face against steel.

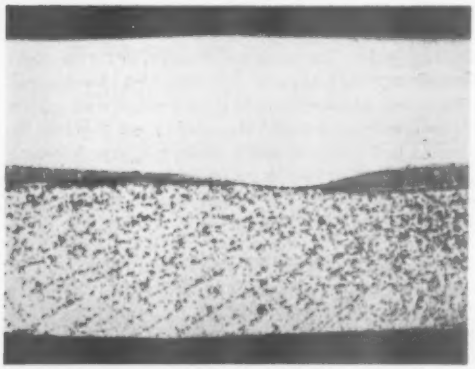


Fig. 5.37 (a) Seam weld made under above conditions, 5½ welds per inch

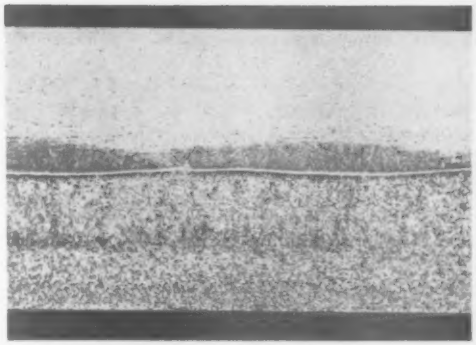


Fig. 5.37 (b) Braze weld Monel to steel. 18 ×. Weld speed—7 welds per inch; or 34 in. per minute

The resultant weld was an intermittent braze type weld shown in Fig. 5.37 (*a*). In this particular instance there was no need for a gas-tight weld. When a conventional type nugget was obtained, major porosity and cracking resulted, such that the weld actually leaked through the Monel sheet.

5.4 Defects

The weld defects, discussed in section 3.4 for spot welds, can be found in seam welds also. The causes and cures are discussed at some length there and will not be repeated here. Generally the same cures can be applied to defects in seam welds.

Since one additional variable—wheel speed—has been added in the case of seam welding, this also adds one additional possible defect—spot spacing. When a gas-tight seam weld must be obtained, and the spots are not overlapping sufficiently to produce the gas-tight seam, they may be closed up by:

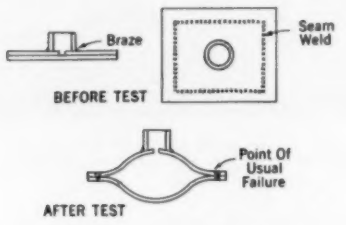
1. Increasing the current to produce a larger spot.
2. Decreasing the wheel speed to produce more spots per inch.
3. Decreasing the "off" time.
4. A combination of the above.

5.5 Tests for Seam Welds

5.51. The tests mentioned in Section 3.5 for spot welds specifically, visual, radiographic, peel and macroetch, can be applied to seam welds to judge their quality. The mechanical tests are seldom applied to seam welds because they are not capable of distinguishing between a good and a bad weld. Almost any seam weld with reasonable quality will fail in a tension shear test by tearing in the sheet outside the weld. The value of tensile strength therefore has little meaning. It is only when stitch welds are tested that shear tension tests are employed.

5.52. The strength of a seam weld is seldom of prime importance, but the leak tightness is. Therefore, most

seam welds are pressure tested for leak tightness. The simplest form of pressure test is the "pillow test" in which two flat sheets are seam welded around the periphery to form a closed container. A hole is drilled in one sheet, approximately central, and a threaded connection is brazed or welded over the hole. Water under pressure is forced through the fitting and the "pillowing" begins.



If the seam weld is faulty, it will leak with practically no distortion of the sheets. A good weld will not fail until there has been a great amount of pillowing and then the failure will occur by tearing of the sheet material adjacent to the weld and usually at a wrinkle in the sheet. There is no attempt made to grade the quality of the weld by the maximum pressure attained before failure. The thickness of the sheet and the size of sheet determine the amount of stress applied at a given pressure.

5.53. If the structure being welded is a closed container, it is frequently pressure tested as a unit. In this case the internal pressure to cause failure is some guide to the quality of weld since all tests are on similar structures and comparison can be made on past performance.

6. FLASH WELDING

Flash welding is a process which produces a butt-type joint in contrast to the lap-type joint obtained by the other resistance-welding processes. In addition, properly made flash-welded joints contain no dendritic material (metal which has been melted). These two features of the flash-welding process are extremely useful for producing equipment which is intended for corrosive service. The butt-type weld has no incipient crack in which corrosion can start. The absence of dendritic material means that the welds will not be preferentially attacked as is the case frequently where fusion type welds are employed. Some examples of flash weld applications are: Monel pickling chains made from bar stock up to 1 in diameter, the side seam of Monel hot water tanks and Inconel rings for jet turbine engine use.

Flash welding is accomplished on a machine which differs considerably from spot or seam welders and yet which involves many of the same features. The parts to be welded are firmly held in relatively massive copper alloy jaws or dies, which maintain the correct alignment. One jaw is fixed while the other is movable, being actuated by hand, by cam or by hydraulic action. The secondary circuit of a large welding transformer is connected to these jaws. At the start of welding, the workpieces are separated so they do not touch, and the voltage is applied to the primary of the welding transformer. As the movable jaw is advanced, the workpieces make contact under light pressure. The heavy current passing through this first contact point causes the metal to melt and then be expelled violently. The particles of metal expelled and the flash of the arc form a spectacular display and are responsible for the name flash welding. As material is burned off the movable jaw is advanced so that flashing continues. When the flashing has continued long enough for the base metal to be heated to the welding temperature, the movable jaw brings the workpieces together with great force. The flashing stops. This is called the upset period because the hot metal in the weld area is upset and the dendritic material in the weld is extruded by the force of upsetting. The current is then turned off and the weld is complete. The jaws are unclamped, the workpieces removed and the machine returned to position for a new weld.

The above flash-welding procedure includes all the fundamental operations which are necessary in any flash welding operation. In very large sections it may be necessary to preheat before the start of flashing. This may be done by shorting the workpieces at a low energy level or heat may be applied from some external source such as oxyacetylene flames. In some operations the entire flash welding cycle is done under an inert atmosphere of argon or helium to eliminate the formation of oxides. This inert atmosphere is not used to any great extent and the beneficial claims are somewhat unproved. Since none of the high-nickel alloys harden upon rapid quenching, it is not necessary to perform a postheating operation after welding, although this operation can be accomplished in the machine and is frequently performed after welding hardenable steels.

Upset-butt welding can be accomplished on the same machine. In upset-butt welding the workpieces are prepared with clean, carefully machined surfaces on the abutting ends. The parts are clamped in the dies and brought into contact under high pressure. The current is turned on and the pieces heat by resistance alone. As the temperature increases, the material expands and the pressure first rises and then tends to fall off as softening takes place. The force is increased and forging and upsetting takes place. The current is turned off and the weld is complete.

Upset-butt welding is seldom done on the high-nickel alloys because of the tenacious oxide which is difficult to reduce and which tends to remain at the joint line in the weld. This line of oxides produces a low-strength weld. If means could be found to obtain a reducing atmosphere at the joint, upset-butt welding could be used but its economic advantage over flash welding is questionable.

6.1 *Design Considerations*

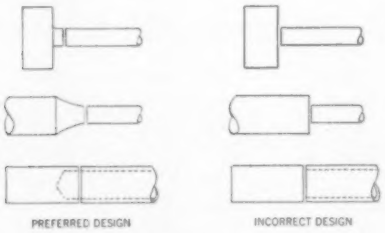
Flash welding can be made automatic so that very little operator skill is required. Since the operation is very rapid, the labor cost per weld is extremely low. However, the first cost of equipment is high and a large volume of joints of a similar nature is necessary in order that the equipment cost per weld will be low enough to justify the use of the process.

In making a flash weld, metal is lost during the flashing and additional metal is lost during the push-up. The over-all shortening of the pieces must be taken into account in designing if the parts are to finish to the correct dimension. The total shortening varies from one to six times the thickness of the parts being flash welded, the greater amount being necessary for thin material. The loss in length during push-up is from one-quarter to one-third of the total. Where specific procedure information is not available, it is wise to make trial welds to determine flash-off and upset losses before settling on the parts dimensions. The flash and upset from the welding operation usually must be removed. This is particularly true for materials to be used in corrosive environments. Sometimes special flash trimmers are used as for welded plate stock. More often grinding or filing are the operations required.

In many flash welding applications there is no need for special preparation of the abutting pieces. Sheared edges of sheet, square saw cuts of bar stock and pinched wire or rod are satisfactory for welding without further machining. In some instances where the section is large or on tubing where inside flash would be troublesome, a beveling of the parts is desirable to facilitate the start of flashing. When pinched-off wire or bar stock is employed, the chisel ends should be placed at 90° to each other.

Preferred Juxtaposition Of Pinched Off Bar

When a large section must be joined to a small section by flash welding, it is best to make the joint in a section of uniform size, thus:



Flash welding is particularly valuable in making joints between many dissimilar metals. There is little or no dendritic material left in a properly made flash weld and little diffusion alloy is formed. Consequently, a satisfactory weld can be obtained without the presence of a cast material having undesirable properties. Figure 6.1 illustrates a ring made from Monel, nickel, K Monel, Inconel, 347 Stainless and S.A.E. 1020 steel. This is merely an illustration of what can be done. The photomicrographs illustrate the sharp demarcation line at the weld interface.

A joint efficiency of 95% is common for flash welding. The strength of a flash weld will approach the strength of the annealed material. Obviously it is not possible to flash weld without annealing a portion of the material adjacent to the weld. For age-hardenable material such as K Monel, Duranickel and Inconel X, the weld will respond to heat treatment as would annealed base material.

6.2 *Equipment Considerations*

6.21 Dies. Flash-welding dies have three functions, namely:

(*a*) To feed current to the piece.
(*b*) To hold the pieces in rigid alignment.
(*c*) To transmit the forging force.

Since electrical conductivity is of prime importance, flash-welding dies are made of copper or a copper alloy with as high an electrical conductivity as can be obtained consistent with hardness and strength. Wherever possible current should be fed to the workpiece from both sides of the die in order that current densities may be kept as low as possible. Too high current density in the work at die edges results in localized melting of the work, or "die burns." The dies should be water cooled to prevent their mushrooming in use.

The dies should be kept scrupulously clean. Any flash settling on the die faces must be removed in order that die burns will not result in the workpieces. See Fig. 6.21 (*a*) and 6.21 (*b*). This usually means a cleaning operation on the dies must be performed after every weld.

The dies must be strong and rigid enough to hold the workpieces in alignment during welding. "Overshooting" may result if the dies are not rigid. See Fig. 6.21 (*c*).

The dies must prevent slipping during the upset period. If possible, permanent stops should be used in

Fig. 6.21 (a) Photograph showing a ½-in. diameter Inconel flash weld bent to open the die burns on each side of the weld

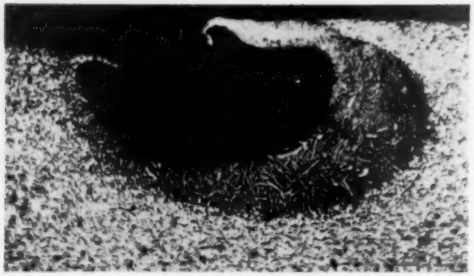


Fig. 6.21 (b) Typical photomicrograph of a die burn in a 1/4-in. diameter K Monel weld showing the crack and previously melted region. 50 ×

Fig. 6.21 (c) Overshooting

order that the dies need not hold the piece by clamping friction alone. Sometimes insulated tool steel teeth may be used in addition to the current carrying dies to obtain greater traction. It is common to have a clamping pressure three times the forging pressure when friction alone must hold the pieces.

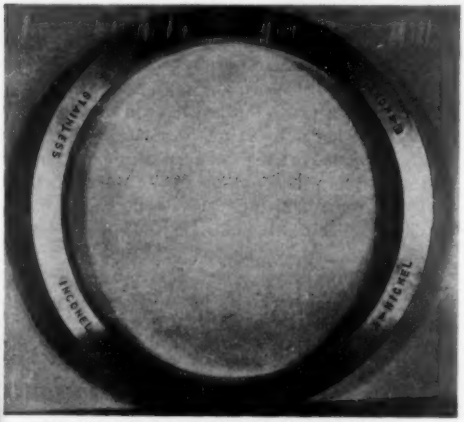
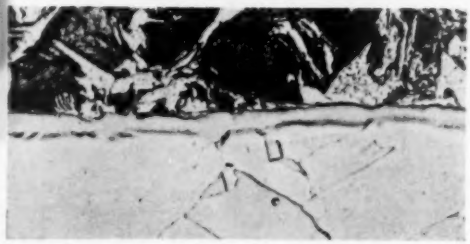
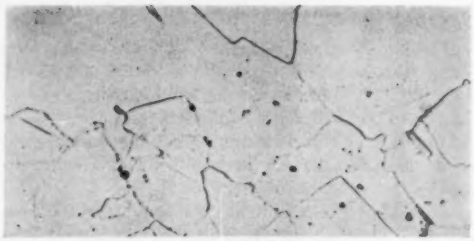


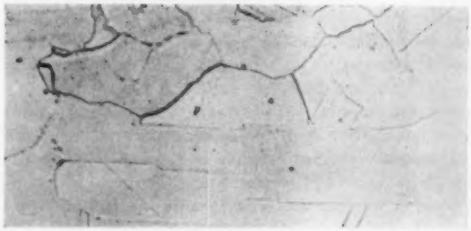
*Fig. 6.1 Flash welded dissimilar metals ring.**



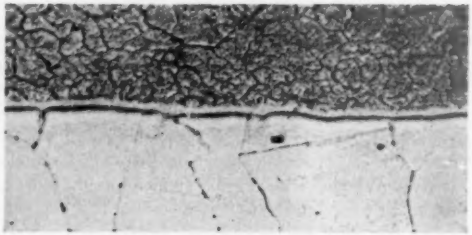
Specimen 1
Top—1020 steel; bottom—B Monel. 500 ×



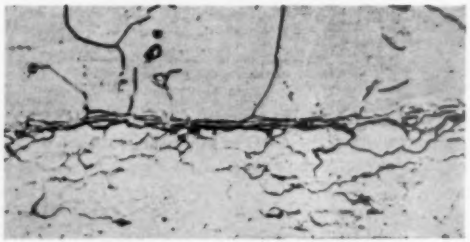
Specimen 2
Top—A nickel; bottom—B Monel. 500 ×



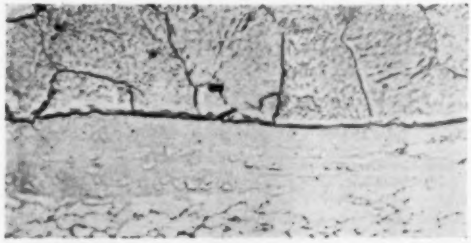
Specimen 3
Top—K Monel; bottom—A nickel. 500 ×



Specimen 4
Top—Inconel; bottom—K Monel. 500 ×



Specimen 5
Top—347 stainless steel; bottom—Inconel. 500 ×



Specimen 6
Top—1020 steel; bottom—347 stainless steel. 500 ×

* Welded by American Welding & Mfg. Co., Warren, Ohio.

6.22 Current and Control. The voltage and current requirements at the start of flashing are high in order to initiate flashing. As flashing progresses this high level of energy input is not needed. A further reduction in energy input is desirable during upsetting. On older types of machines where the energy level is selected by taps on a transformer, a compromise setting must be employed since no change can be made during the flashing cycle. On more modern machines, with ignitron control, a change of energy level can be made at any time. Such machines produce more consistent welds, and avoid these difficulties.

(*a*) If the energy level is too low at the start of flashing, "freezing" may occur. This freezing, frequently called "butting," means that the arc has been extinguished and a large volume of metal is being heated by resistance heating. This large volume will usually melt and drop out and no weld will result. The available energy level during flashing must be so related to the flashing speed that butting does not occur at any time during the flashing portion of the weld cycle.

(*b*) If the energy level is too high during flashing just prior to upset, the particle size of the flash will be coarse and there will be more chance for oxidation of the larger pits formed during flashing. Such oxidized areas may not be extruded during upset, and the resulting weld will have voids or trapped oxide and low strength.

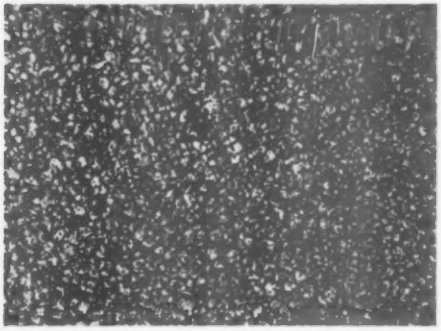


Fig. 6.22 (a) Photomicrograph showing the "overheated" region in a K Monel flash weld resulting from excessive butting. 100 ×

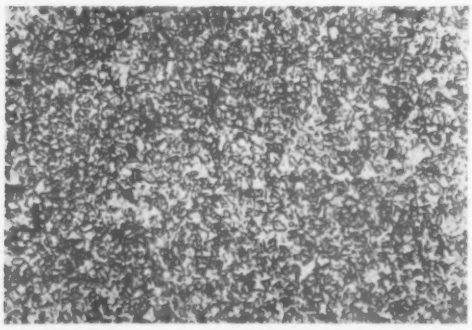


Fig. 6.22 (b) K Monel parent metal. 100 ×

(*c*) If the energy level is too high during upset, the timing of current cut-off after upset is very critical. Too long a time and the material will be spoiled by overheating. See Fig. 6.22 (*a*). Too short a time, especially current cut-off prior to the initiation of upset, results in severe oxidation of the weld interface, and the material is not soft enough to forge properly. On older machines this time of current cut-off after upset is in the order of 2 to 4 cycles.

6.23 Pressure Requirements. The pressure required for flash welding nickel and the high-nickel alloys is generally higher than that required for mild steel and is in the order of 35,000 psi. The function of pressure during push-up is to forge the weld by plastic deformation and to extrude all oxidized material and material which has been molten from the weld. If insufficient pressure is employed, the welds may contain voids, oxidized metal and some cast structure. See Fig. 6.23 (*a*) and 6.23 (*b*). On the other hand, if too much pressure is employed, the machine attempts to make a weld where the material is not sufficiently plastic. A poor weld results.

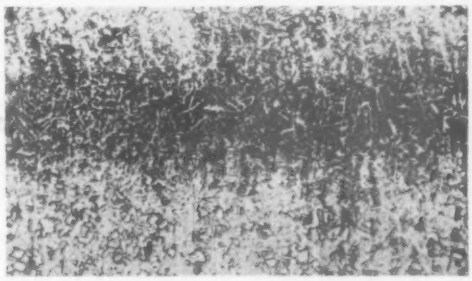


Fig. 6.23 (a) Typical example of a trapped dendritic material in a K Monel weld made with insufficient upset. 100 ×

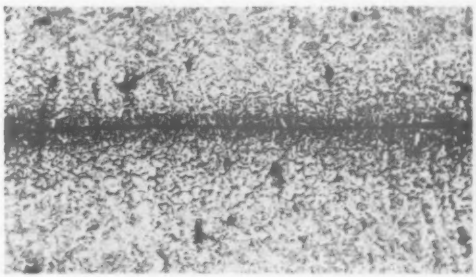


Fig. 6.23 (b) Continuous oxide layer in a Monel weld produced by interrupting the current prior to upset. 100 ×
Example of self-nesting

6.3 Welding Procedure

Material to be flash welded must be clean and free of oxides, grease, oil, paint and other foreign material (see section 2.2). Oxide on the surface of bars or sheet may form a hot spot where the die clamps the work. Such hot spots can cause die burns. (See Fig. 6.21 (*a*).)

TABLE 6.31
Recommended Conditions for Flash Welding Nickel Alloy Rods

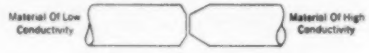
Material	Rod Diam., In.	End Preparation*	Flashing Distance, In.	Flashing Time, Sec.	Current Duration During Upset, Cycles	Upset Distance, In.	Watt Hrs./Weld	Weld Strength, Psi.	Rod Strength, Psi.
Nickel	1/4	Pointed	0.442	2.5	1½	0.125	2.15	58,000	65,100
Nickel	3/8	Pointed	0.442	2.5	2½	0.145	4.87	65,600	66,500
Monel	1/4	Pointed	0.442	2.5	1½	0.125	1.93	68,500	70,500
Monel	3/8	Pointed	0.442	2.5	2½	0.145	5.55	80,300	84,700
"K" Monel	1/4	Pointed	0.442	2.5	1½	0.125	2.02	93,900	100,000
"K" Monel	3/8	Pointed	0.442	2.5	2½	0.145	4.79	98,800	99,000
Inconel	1/4	Pointed	0.442	2.5	1½	0.125	2.15	101,200	109,800
Inconel	3/8	Pointed	0.442	2.5	2½	0.145	5.19	102,000	106,000

* 110° included angle.

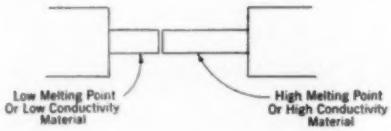
6.31. Table 6.31 gives the recommended conditions for flash welding 1/4- and 3/8-in. diameter nickel, Monel, K Monel and Inconel bars. This data was developed on an old type of equipment where the current could not be adjusted during the welding cycle. In such equipment the time of current flow during upset is quite critical to avoid burning the material.

6.32 Welding Dissimilar Metals Combinations. It is possible to flash weld many dissimilar metals combinations which would not be possible by other welding processes due to the absence of dendritic material. (See Section 6.1.) It is difficult to give specific machine settings for dissimilar metals joints but a few general statements may be of help in obtaining proper welds.

When dissimilar materials are being flash welded, it is sometimes helpful to have a different end preparation for each of the two different materials, thus:



It may also be necessary to extend the workpieces different distances from the dies in order that the two pieces will come to a welding temperature at the same time, thus:



6.4 *Defects*

Under certain conditions, the following defects can be found in flash welds:

6.41 Die burns.
6.42 Dendritic material inclusions.
6.43 Oxide inclusions and voids.
6.44 Burned material.
6.45 Cracking.
6.46 Low-strength welds.

6.41. Die burns have been mentioned already in Par. 6.21. They are caused by:

(*a*) Dirty material.
(*b*) Fouled dies.
(*c*) Inadequate clamping pressure or die area.

Visual examination is sufficient to disclose the presence of die burns. To eliminate, clean the material (see Par. 2.12), clean or redress the dies (see Par. 6.21), and be sure the dies clamp the workpieces with suitable pressure over as large an area as possible.

6.42. Dendritic material inclusions may be caused by:

(*a*) Insufficient upsetting pressure or movement.
(*b*) Forging at too low a temperature.
(*c*) Improper parts preparation.

The best method of discovering the presence of dendritic material in the weld is to section the weld in a plane or planes perpendicular to the weld, polish and etch, and examine under a microscope. To eliminate, use greater forging pressure and/or forging distance, increase the upset current, or increase the time of current flow after upset, or prepare the parts with a shallower included angle.

6.43. Oxide inclusions and voids are the result of:

(*a*) Inadequate upset.
(*b*) Too high an energy level during flashing which results in expulsion of large particles, leaving holes and oxide which will not be removed by upsetting.
(*c*) Too low an energy level which results in attempting to upset metal which is too cold.
(*d*) Current cut-off prior to upset.

To eliminate, increase the upsetting pressure, increase the upsetting current, increase the time of current flow after upset and adjust the flashing power level.

6.44. Burned material is the result of too much heat in the flashing or upset portion of the welding cycle. It may be caused by:

(*a*) Too long a flashing time.
(*b*) Too long a time of current flow after upset.

To eliminate, reduce the time of current flow after upset or shorten the flashing time.

6.45. Cracking may be caused by attempting to forge material too cold or too hot. Not infrequently the cracks are entirely contained within the flash and will be machined off. Such cracks are not defects. To eliminate real cracks, obtain a proper welding cycle.

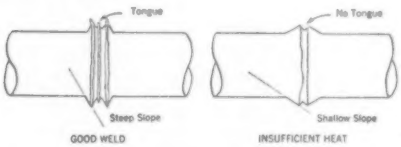
6.46. Low strength may result from the above-mentioned defects or form attempting to forge material which is too cold. The machine variables must be adjusted to eliminate.

6.5 Tests for Welds

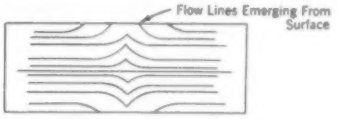
The following are commonly used tests of flash welds:

6.51 Visual.
6.52 Sectioning, etching and macro examination.
6.53 Bending.
6.54 Tensile.
6.55 Proof test.
6.56 Other tests.

6.51. Visual examination will disclose die burns, cracking and, in addition, will give some indication of the quality of the weld. A steep slope in the upset area adjacent to the weld is an indication that sufficient heat has been employed. Too low a slope will indicate a weld made under cold condition. A well-made flash weld will usually have a "tongue" discernible between two ridges of flash.



6.52. Sectioning, etching and macro or micro examination is probably the most useful inspection tool for flash welds. Etchants as given in Par. 3.515 may be used. Such an examination will show dendritic material, voids and oxides (if at the section), burnt material and flow lines in the bar stock. In regard to flow lines, it is not advisable to forge so much or so cold that the flow lines are turned 90° and emerge from the surface. Low fatigue strengths have been reported for such welds.



6.53. A simple shop test which consists of bending the welded joint is frequently used to disclose low-strength joints. It does not always disclose what is the cause of the low strength.

6.54. Tensile tests of 0.505-in. specimens machined from the joint are frequently employed to obtain unit mechanical properties.

6.55. A proof test is also popular in which the joint is subjected to a load which is in excess of the expected working load but which will not fracture a good weld.

6.56. Other special tests are employed for special purposes such as fatigue, impact, magnetic particle and others. Radiographing of a flash weld is seldom done because it is difficult to disclose faults other than voids which will be detrimental to the weld.

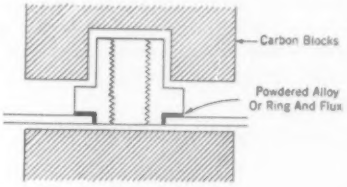
7. RESISTANCE BRAZING

Spot-welding machines may also be employed as a source of rapid heat for silver brazing small assemblies. It is often possible to use a transformer and suitable fixture without the need for such elaborate pressure or current controls as are needed in spot welding.

Heating for resistance brazing is accomplished by passing a relatively large current through some high-resistance materials which in turn contact the work parts. The current passes through the parts to be brazed but the majority of the heat is generated in carbon or tungsten electrodes and this heat travels by conduction to the workpieces. The currents used are much less than employed for spot welding and the time is much longer.

7.1 Design Considerations

Wherever possible, the parts should be designed to be self nesting. A little thought in the design stage will eliminate the need for fixtures in the brazing operation.



Example of self nesting

Work to be brazed must be thoroughly clean. (See Par. 2.2.)

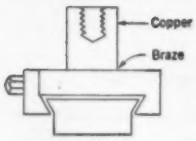
Any silver brazing alloy not also containing phosphorus may be used in the form of wire or strip or powder. The flux used must be very fluid and should not be allowed to dry out prior to placing the parts in the brazing fixture, otherwise it will be difficult to pass current.

Parts should be annealed prior to brazing and no stress should be placed upon the parts during the brazing process.

7.2 Equipment Considerations

Carbon blocks or rounds are generally used for the brazing electrodes though for more permanent installations, tungsten or molybdenum may be employed. A good grade of block is Grade AGX of National Carbon Co. Other grades with softer or harder qualities and with different electrical resistances may be obtained. The blocks may be easily shaped with a file and saw and are to be considered quite expendable since they waste away quite rapidly.

The carbon blocks should be fastened mechanically to a water-cooled holder of the spot welder.



For extremely fine work, plier-type brazing equipment is available* with many different types of heating arrangements.

Relatively long times are required, from 1 sec. to 2 min. Usually the operator judges time by watching the temperature of the piece. When the flux and alloy have melted the current may be turned off. If an extension timer is available to produce such long times, the spot-welder panel may be used to get consistent results.

7.3 Brazing Procedure

The parts to be brazed must be clean and free from grease, oil, oxide and other foreign material. (See Par. 2.2.)

The alloy may be preplaced in the form of wire, rings, strip, washers or powder. Flux is employed in a very fluid form and is put on the assembly just prior to brazing. If the flux is allowed to dry it will be difficult to make the current flow since dry flux is a good insulator. When powdered alloy is employed it is sometimes mixed with the flux in a shallow pan. The part to be brazed is dipped into the flux and alloy just prior to placing it in the fixture. In some applications the alloy may be stick fed by hand as the parts come up to temperature.

* General Electric Co.; Ideal Commutator Dresser Co.

The amount of current used is such that heating will be uniform and not too slow or too fast. The time of current flow is not critical. As the pieces heat, the flux first dries, then becomes molten and then the alloy flows. When a suitable fillet is formed by the alloy, the current is turned off but the pressure is maintained until the alloy solidifies. A pressure heavy enough to make good electrical contact but light enough not to crack the blocks is employed.

The parts are lifted out with tongs and quenched in order to cool rapidly and to remove the residual flux.

7.4 Inspection Procedure

The brazed parts are inspected visually for full and continuous fillet. Once in a while it is well to break a joint to determine strength and the absence of flux entrapment. Some parts may also be pressure tested.

More complete information concerning silver brazing will be found in Technical Bulletin T-34.

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(*Continued on page 716*)

Fundamentals of Inert-Gas-Shielded-Arc Welding

Fundamentals and major developments in inert-gas-shielded-arc welding, present stage of application and expected future trends

by H. E. Rockefeller

INERT-gas-shielded-arc welding, which includes the use of a consumable as well as a nonconsumable electrode, has, in slightly over a decade, become one of the major fusion welding methods. For the nonferrous and "difficult to weld" metals, it has or is rapidly becoming the generally preferred fusion welding method. It has not only largely replaced other methods, but has permitted fabrications hitherto impracticable for welding. Inert-gas-shielded-arc welding has also invaded certain fields in the welding of stainless steels, alloy steels and even carbon steels, and there are indications of a much broader application of the process in the welding of these metals.

It may be appropriate at this time, therefore, when defense needs will undoubtedly present many new welding problems, to review briefly the fundamentals of this process, the major developments which have brought it to its present stage of application and the expected future trends.

HISTORICAL DEVELOPMENT OF INERT-GAS-SHIELDED-ARC WELDING

The nonconsumable electrode type of inert-gas-shielded-arc welding, named "Heliarc," was first commercially established in California in 1940 by the Northrup Aircraft, Inc., for their own application in the welding of magnesium for aircraft fabrication. Recognizing the possibilities of this process, Linde, in 1942, acquired the Northrup invention, and initiated an extensive research and development program to expand the use of the process. In the initial investigations, it was established that argon offered several advantages over helium as a shielding gas. Argon, being approximately ten times as heavy as helium, gave more complete protection at a considerably lower gas flow.

Contrary to assumptions which have been made by others, the argon in inert-gas-shielded-tungsten-arc welding is not heated sufficiently by the arc to lower its density to that of the surrounding air. Schlieren measurements of the gas pattern of argon issuing from the cup have been made both with and without the welding arc present. In the case of patterns taken without the arc present, the gas was preheated before entering the nozzle in various amounts to simulate the gas pattern established with the arc present. It has been concluded from this work that the argon is not heated by the arc to a temperature above 300° F. With the arc present the argon at recommended gas flows hugs the surface being welded in contrast to helium which tends to rise rapidly from the weld zone. This is illustrated in Fig. 1.

The tungsten arc in argon is more stable than in helium. This basic difference in these two monatomic gases has been observed by several investigators. This greater arc stability, combined with the lower arc voltage in argon, gives a more readily controlled welding zone. This latter feature is of particular advantage in manual welding. Argon was also found to provide a much improved oxide cleaning action in a.-c. welding of aluminum. For these reasons, argon soon became and continues to be the monatomic gas predominantly used in this process.

Aluminum appeared to offer one of the broadest fields of application and much of the early research and development effort was devoted to establishing suitable Heliarc welding conditions for the metal. It was found that with the d.-c. welding used by Northrup in the welding of magnesium, satisfactory results could not be obtained with straight polarity and that electrode heating with reverse polarity materially reduced the welding speed obtainable. It was recognized, however, that a good cleaning action was obtained in reverse polarity welding which effectively removed the aluminum oxide when using argon. Through the use of a.-c. welding, a very satisfactory compromise was established in that the reverse-polarity cycle provided the cleaning action and the straight-polarity cycle improved the heat input to the weld with consequent material increase in welding speed and higher current-carrying capacity for the electrode. It was further established that by superimposing a high-frequency current on the welding current the arc could be established without touching the metal. This eliminated contamination of the electrode and also stabilized the arc during the welding operation.

In the Heliarc welding of all other metals except magnesium, and aluminum bronze, on which alternating current is also preferred for most applications, direct current

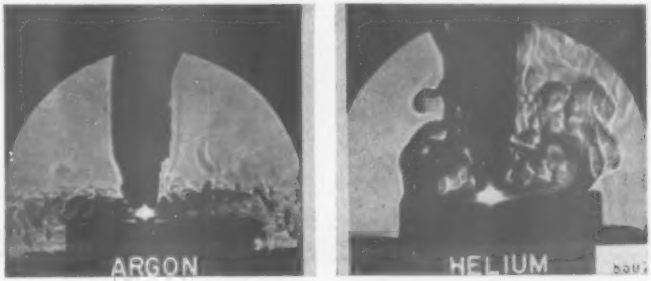

Fig. 1 Schlieren photographs of tungsten arcs in helium and argon atmospheres

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straight polarity generally provides the most satisfactory and efficient power source.

HELIARC WELDING EQUIPMENT—OLD AND NEW

The development of suitable equipment has also played an important part in the acceptance of Heliarc welding. The original torches were air-cooled and were suitable only for direct-current welding at relatively low currents. One of the earlier models is illustrated in Fig. 2. This torch was used during World War II for the welding of magnesium castings and has a maximum current-carrying capacity of about 100 amp. Two developments did much to overcome the limitations of this design. The first was the development of the ceramic cup and the second, the invention of a water-cooled current-carrying cable and torch. These two developments are illustrated in Fig. 3. They not only provided an assembly which maintained the desired flexibility for manual welding at currents up to 175 amp. but permitted the practical use of superimposed high frequency so important in a.-c. welding of aluminum. Water-cooled metal cups were next developed which permitted the current range in manual welding to be extended to 700 amp. although 500 amp. is the maximum demanded except for special applications. Such a torch is illustrated in Fig. 4.

There has been a demand for a small torch for welding light-gage materials such as jet-engine parts. The torch developed to meet this demand is illustrated in Figs. 5 (*a*) and 5 (*b*). This torch is air-cooled and has a current-carrying capacity of about 75 amp. It weighs but 3 oz.

While no mention has been made of Heliarc machine welding, or machine torches, a number of important applications have been made. The over-all growth of the Heliarc process, however, has been predicated on the use of manual equipment just as it has in coated-metallic-arc and oxyacetylene welding.

INTRODUCTION OF SIGMA WELDING

In 1948, after the Heliarc process had become broadly accepted, and with several thousand installations in service, the shielded-inert-gas-metal-arc process was introduced by the Air Reduction Co. This process employs a consumable electrode in place of the nonconsumable electrode used in the Heliarc process. The electrode is continuously fed from a rod reel similar in principle to submerged-melt welding except that the inert gas replaces the granular welding composition. The original equipment was of a semiautomatic type wherein the electrode was fed through a flexible cable to a manually operable torch. Linde soon afterward introduced a fully automatic unit, and later, followed with a semiautomatic unit.

The shielded-inert-gas-metal-arc process, which we propose to call "sigma welding" from the initial letters of the five words, was applied first to aluminum. Subsequently it has been commercially applied on stainless steel, copper and copper alloys including silicon and aluminum bronzes, and even on carbon steel. The process is less than three years old and can still be said to be suffering somewhat from growing pains. The largest commercial use at present is in the flat-position welding of aluminum. On this application, and with argon as the shielding gas, quality comparable to that obtained with the Heliarc process is readily secured, particularly with the fully automatic equipment. A large amount of laboratory data have been accumulated and some commercial application has also been

Fig. 2 An early style air-cooled torch used with direct current, reverse polarity in the welding of magnesium castings during World War II. Maximum capacity about 100 amperes

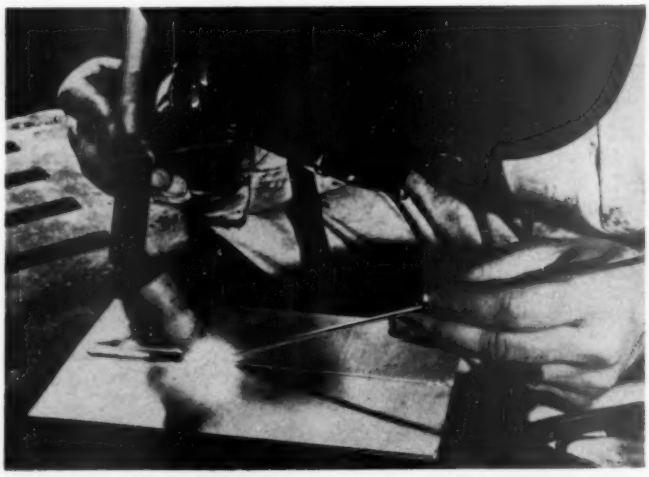


Fig. 3 The first water-cooled torch using a water-cooled cable and ceramic cup. Maximum capacity about 300 amperes

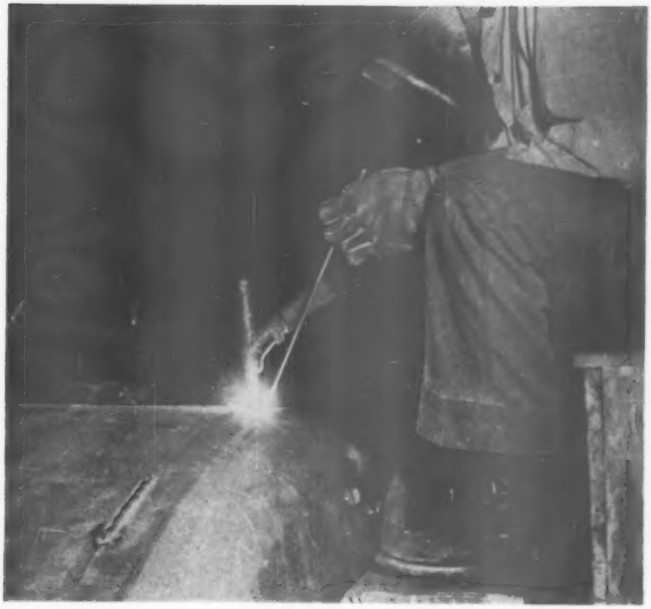


Fig. 4 A torch of type similar to that in Fig. 3 but having a water-cooled cup and a current capacity of about 500 amp.

made on stainless steel, copper and copper alloys. On these metals it is generally recognized that argon gives a weld quality and deposition control superior to that which can be obtained with helium. With argon, a more stable arc can be maintained with a lower gas flow and much less spatter. Considerably higher rates of metal deposition can be made in sigma welding than in Heliarc welding, and welding costs, therefore, are appreciably less.

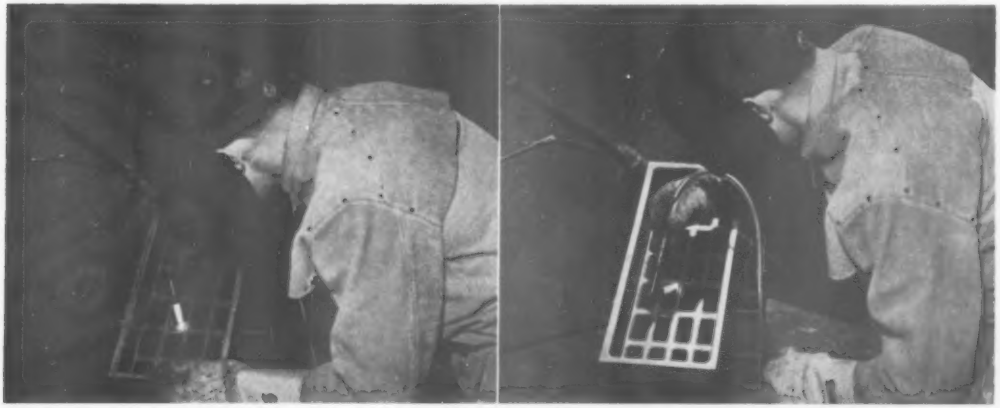
COMPARISON OF HELIARC AND SIGMA WELDING

There are several characteristics in inert-gas-shielded-arc welding which distinguish this process from other fusion welding methods. There are, furthermore, certain fundamental differences between the nonconsumable electrode (Heliarc) method and the consumable electrode (sigma) method. These characteristics have largely determined the already widespread application of Heliarc welding and the growing commercial use of sigma welding.

Probably the most important characteristic common to both Heliarc and sigma welding is the elimination of flux and resulting slag. Fluxes required by other welding processes for welding aluminum, magnesium and some other metals contain constituents which are corrosive to the base metal if not removed after welding. Their removal from the weld surface adds cost to the over-all fabrication. Such removal, furthermore, is often difficult and for certain joint designs, impracticable.

Another important difference in inert-gas-shielded-arc welding is the characteristic higher current density employed. In Heliarc welding average current density recommended is about ten times that recommended for carbon-arc welding, and about three times that recommended for coated-metal-arc welding. In sigma welding the current densities employed average at least twice those used for Heliarc. This results in the permitted use of an exceedingly high heat concentration with a consequent ability to secure deep penetration, narrow welds, a smaller heat-affected zone and reduced distortion.

In Heliarc welding, the use of a nonconsumable electrode permits joining of metals without the addition of filler wire at generally lower costs and with less distortion than with oxyacetylene, atomic hydrogen or carbon arc welding. Where filler wire is required the replacement of the weld metal in butt welding can be more accurately controlled than in the coated electrode or sigma welding, and finishing costs may be reduced when smooth finishes are required. This characteristic of separate control of heat input and addition of filler metal in Heliarc welding also permits of better control of



Figs. 5 (a) and 5 (b) The jet engine demands a small torch for welding light materials for which this non-water-cooled torch was developed. Current capacity about 75 amp.

the elimination of gases which may be evolved from the base metal during the welding operation.

In sigma welding, on the other hand, a better heat transfer efficiency is obtained than in Heliarc welding because the added metal is carried over in the molten state in the arc stream rather than heated from the nonconsumable electrode or molten puddle. Furthermore, the current densities are not limited by the melting temperature of the tungsten electrode. These characteristics result in higher rates of metal deposition, lower costs and higher weld zone cooling rates than in Heliarc welding. Quality of the deposited metal has been generally more difficult to control because of the critical nature of the manner of metal transfer.

It has been established that for best welding conditions, metal transfer consists of a series of discrete metal droplets propelled at a high velocity. This droplet formation varies for different metals and for different current densities. An intensive research has been under way for some time to determine factors that affect the droplet rate and size for different metals since it is believed that the commercial growth of sigma welding may well be determined by the extent to which the droplet formation can be controlled.

Our research has shown that the droplet rate particularly on stainless and carbon steels can be materially increased by the addition of small percentages of oxygen to a highly purified argon. Droplet rate in this oxyargon mixture has been as much as 50 times greater than in an atmosphere of pure argon, other conditions being the same.

This greatly increased droplet rate, with no change in current density, permits welding at higher speeds without undercutting. Coalescence of the weld metal is improved at increased welding speeds. Overhead welding of stainless steel is made practicable.

On the other hand, the oxyargon mixture permits welding at lower current densities. This means that larger diameter, more economical rods may be used for a given welding current. If the same size rod now available is used, then thinner materials can be welded.

A comparison of welding methods used on the principal metals to which the inert-gas-shielded process has been employed may help to clarify the characteristic features of Heliarc and sigma welding. Discussion will be limited to aluminum, stainless steel, copper and its alloys and carbon steel.

INERT-GAS-SHIELDED-ARC WELDING OF ALUMINUM

The most extensive use of the inert-gas-shielded process to date has been on aluminum and its alloys. Prior to the introduction of Heliarc welding, oxyacetylene or oxyhydrogen welding was employed for most sheet metal and light plate fabricated by butt welding. Carbon arc was in use for mechanical welding of the heavier plate material, and metallic-coated-electrode welding for structural joining and some butt welding.

Heliarc has replaced gas welding for all but certain very light gage applications such as some flanged joints in aircraft construction. It also has largely replaced carbon-arc welding and metal-arc welding for butt welded constructions. Sigma welding has, in turn, replaced Heliarc on certain of the butt welding applications and metallic arc on certain structural weldments. These two variations of shielded-inert-arc welding have also encouraged the fabrication of aluminum on applications for which no other method would have provided either the required quality or economy.

The history of welded fabrication of aluminum tank cars furnishes a good example of the advances in aluminum welding. The first tank cars were fabricated by oxyacetylene welding. This process was later replaced by mechanized carbon-arc welding, which then gave way to Heliarc welding. Within the past two years, Heliarc welding, in turn, has been replaced largely by sigma welding. Fig. 6 illustrates the use of Heliarc welding. In Fig. 7 the fully automatic equipment with consumable electrode is shown. These vessels are constructed to specifications equivalent to the A.S.M.E. Pressure Vessel Code and all welded seams subjected to X-ray examination.

While over-all cost comparisons must include a number of factors other than direct welding costs, the comparisons given in Table 1 are significant in illustrating the possible savings of sigma welding over Heliarc welding in the fabrication of relatively heavy aluminum plate by butt welding. The high duty factor of 70% obtained in mechanized sigma welding vs. the duty factor of 40% for manual Heliarc welding and the higher rate of deposition with less than half the rod required per foot of weld result in a welding cost for sigma welding of about one third that for Heliarc welding.

The welding of aluminum barrels by one fabricator further illustrates the change in welding methods brought about by inert-gas-shielded-arc welding. Here Heliarc welding replaced gas welding for the prin-

Table 1—Cost Comparison, Heliarc vs. Sigma Welding, Costs for 100 Ft. of 1/2-In. Aluminum Plate

	Heliarc	*Sigma*
Welding rate, in. per minute per pass	10	12
No. of passes	3	2
Duty factor, %	40	70
Argon used, cu. ft.	1125	335
Rod used, lb.	14	6
Labor at $2.00 per hour	$ 30.00	$11.40
Gas cost	112.50	33.50
Rod cost	10.40	4.68
Power and miscellaneous	1.00	.75
Total	$153.90	$50.33

Fig. 6 The Heliarc process as used in welding of aluminum tank cars

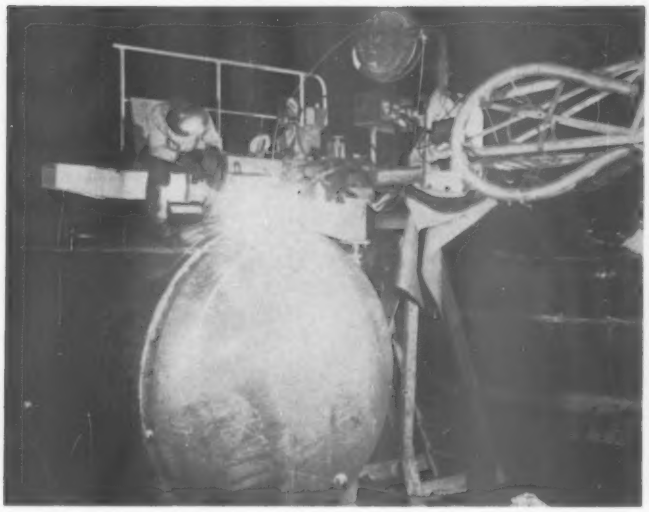


Fig. 7 The sigma welding process which is largely replacing Heliarc welding of heavy material

cipal seam joining the two halves of the barrel, and sigma welding more recently is replacing metal-arc welding for attaching the chimes.

The reasons for the replacement of other welding methods by Heliarc and sigma welding are obvious for the most part but may bear repeating. The elimination of flux has been an important factor. Better welding quality was another. Less distortion and less annealing of the heat-affected zone was a third. Together with these advantages there has been for most applications an over-all reduction in fabrication cost, the most important factor of all.

The reasons for replacement of Heliarc with sigma welding are largely dictated by cost. However, for fillet welding, the sigma process has the added advantage of improved penetration. Quality, on the other hand, still remains the dominant factor on some applications. In sigma welding the problem of controlling porosity has not been completely solved but equipment and process developments are providing suitable answers on selected applications. Research may soon provide an over-all solution to the porosity problem. When this is accomplished sigma welding will undoubtedly become the most economical fusion welding method on all applications of aluminum where the addition of filler metal is a requisite.

It can be generally concluded, therefore, that inert-gas-shielded-arc welding has provided industry with a method of fusion welding of aluminum which permits this metal to be fabricated with the same facility as steel. There remains, of course, a need for further refinement of the equipment and process for the application of sigma welding, but it would appear that the remaining limitations will be overcome, and hopefully, in the near future.

Before leaving the subject of aluminum welding, I should like to give my personal opinion on a method of welding which has recently been given some renewed attention. This involves the direct-current, straight-polarity welding of aluminum with helium. Our findings have indicated that for single-pass welds the aluminum oxide and porosity cannot be eliminated from the bottom of the weld. There obviously is not the same cleaning action as occurs with alternating-current welding of welding with direct current, reverse polarity. Thoriated electrodes are claimed to give improved cleaning results, but our tests do not confirm this. This does not mean that thoriated tungsten electrodes offer no advantage. They do for a number of applications, but for reasons other than improved cleaning action.

WELDING OF STAINLESS STEEL

In the stainless steel field, Heliarc welding has largely replaced oxyacetylene and metal-electrode welding on light-gage material. This is primarily due to lower distortion compared to gas welding, and lower finishing cost compared to metal-electrode welding. Heliarc welding offers a quality advantage over other processes in that there is no loss of stabilizing or other elements and no carbon pickup. Additionally, this process provides a latitude in welding certain compositions which have not been satisfactorily welded by other processes. The Heliarc process may be more costly than metal-electrode welding in applications on materials over $^1/_8$ in. in thickness where other factors do not compensate for the deposited weld metal cost.

Insufficient commercial application of sigma welding to stainless steel fabrication has been made in order to forecast the ultimate use of the process. However, there appears to be no evident reason why sigma welding should not largely replace all other fusion welding methods on plate and structural fabrication.

WELDING OF COPPER AND COPPER ALLOYS

Copper and copper alloy welding seems to be following the same general sequence in preferred welding method that has occurred in the case of aluminum. Satisfactory welding procedures have been developed both for Heliarc and sigma welding and the advantages are relatively the same. Because of the high heat conductivity common to copper and copper alloys, the rapid heat input rate associated with the sigma process shows particular advantage over the Heliarc process in the heavier gages. With the sigma process very satisfactory welds have been made in thicknesses up to $^1/_2$ in. without preheat. A particularly interesting application is the repair of a massive 7000-lb. cast copper mold. As frequently happens in preparing such molds, a defect was uncovered in machining. This was repaired by sigma welding using a hand torch with a preheat of 500° F. A welding current of 400 amp. effected a very satisfactory repair.

WELDING OF CARBON STEELS

The welding of carbon steels has, of course, dominated the application of fusion welding. Statistics show that over 95% of all fusion welding is applied on carbon steels. Considerable interest has, therefore, naturally been shown in the present and future possible application of inert-gas-shielded-arc welding to carbon steels. In the Heliarc field considerable application has already been made for certain sheet-metal weldments. In the automotive industry particularly the Heliarc process has been applied to the welding of fenders, body joints, bumper guards, bumpers and other accessory parts requiring metal finishing. The process has found acceptance in this field because the welds could be produced at high speeds with no porosity, slag, or spatter, a minimum of reinforcement, controlled distortion and low costs. A typical fabrication illustrating a Heliarc welded front fender is shown in Figs. 8 (*a*) and 8 (*b*).

Heliarc welding is expanding in the sheet metal field and tungsten arc semi-automatic rod feed and automatic welding devices will increase the use of the process materially. Speeds of 80 to 100 in. per minute on 20-gage material appear to be entirely practical. Competition is, of

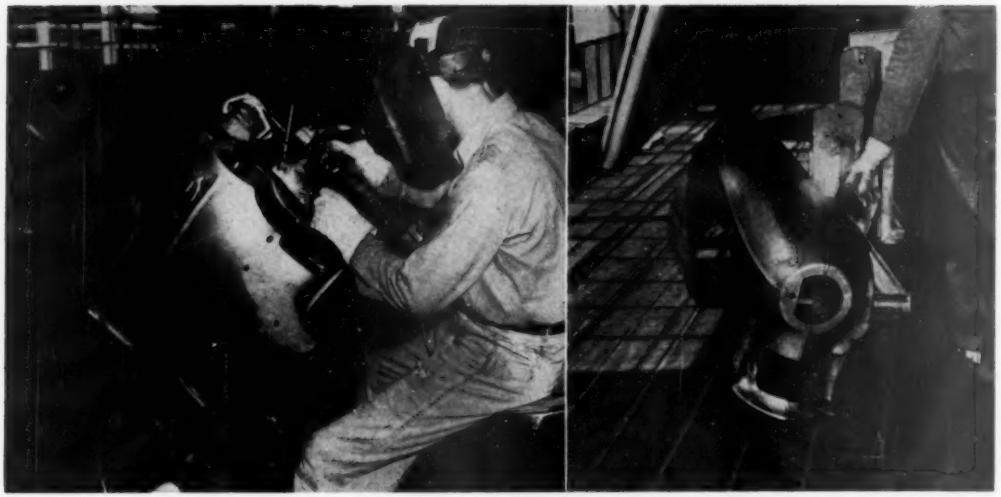


Fig. 8 (a) and 8 (b) The Heliarc process being used in the welding of automobile fenders

course, extremely keen in this field, and because of cost, Heliarc welding will probably be limited to applications where finishing or some other factor favors the Heliarc process in the over-all cost consideration.

The field for sigma welding of carbon steel is as yet unknown, but sufficient laboratory work has been carried out to establish that sound welds can be produced, and at speeds that should provoke considerable commercial interest.

CONCLUSION

As in the case of Heliarc, sigma welding may need a "crutch" to lean on for economic acceptance until welding costs are further reduced. This "crutch" may be in the form of lower cleaning and finishing costs or freedom from contamination due to the slag and spatter resulting from the use of existing processes. Sigma welding is already established commercially for welding aluminum, stainless steel, copper and copper alloys.

The operating factor obtained with this process may be from 50 to 75% higher than obtained with other hand methods. The rate of travel may, in many cases, be as much as twice as fast with this process than other methods.

Other advantages possessed are better heat transfer and, in the case of aluminum, higher rate of deposition with less than half the rod required per foot of weld. Mechanized sigma welding offers attractive advantages in economy of operation. It is confidently expected that sigma welding will be commercially applied to special applications of carbon-steel welding during 1951.

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(*Continued on page 727*)

Characteristics of Inert-Gas-Shielded Metal-Arcs

Studies of the characteristics of inert-gas-shielded metal arcs including relationship between voltage, current and arc length; radiation; material transfer; and stability

by A. Muller, W. J. Greene and G. R. Rothschild

INTRODUCTION

IN ORDER to understand more fully the many complex problems associated with welding arcs a number of investigators have devoted considerable effort to the study and analysis of certain fundamental phenomena relating to the physics of these arcs. Despite this work, which has been in progress for many years, and the much more comprehensive investigations made of other arcs in which material transfer is not of primary importance, basic knowledge of the subject is significantly meager. This lack of information is particularly evident in the field of inert-gas-shielded metal-arc welding with a consumable electrode wire which only has been in commercial use for a short time.

A number of investigations have been initiated to study the characteristics of inert-gas-shielded metal arcs to permit the intelligent application of this method of welding. Certain data and information already developed under this program are presented herein. The term characteristics is used to define the arc in its broadest sense and includes any phenomenon which describes the arc. There are a great many of these characteristics but this discussion is limited to the following:

1. Relationship between voltage, current, and arc length.
2. Radiation.
3. Material transfer.
4. Stability.

A significant feature of the inert-gas-shielded metal-arc-welding process is that direct current with electrode positive must be used to weld the common metals. In all of the work reported, the arc was shielded with either argon or helium flowing at an average velocity of 6 ft. per second.

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VOLTAGE CHARACTERISTICS

Experimental Procedure

To determine the influence of arc length on arc voltage an arc was established in an inert gas atmosphere between a small electrode wire and a flat plate. The electrode was continuously fed by a welding head equipped with a nozzle which directed an axial flow of shielding gas about the arc. A magnified (21 ×) image of the arc was projected on a screen. Figure 1 shows a composite photograph of several images indicating the lengths, *l*, measured. These measurements are electrode-to-plate distances rather than true arc lengths

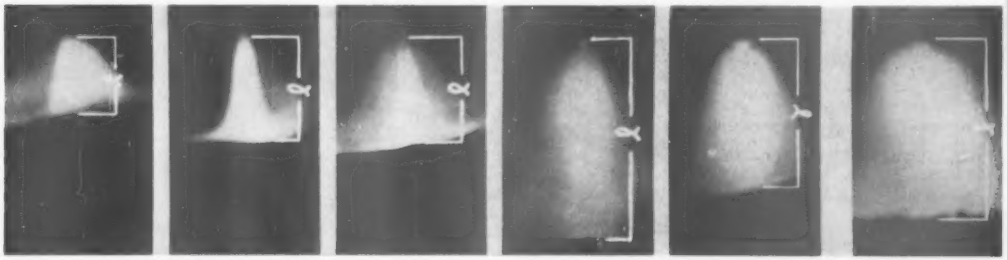

Fig. 1 Lengths, l, measured on magnified (21 ×) image

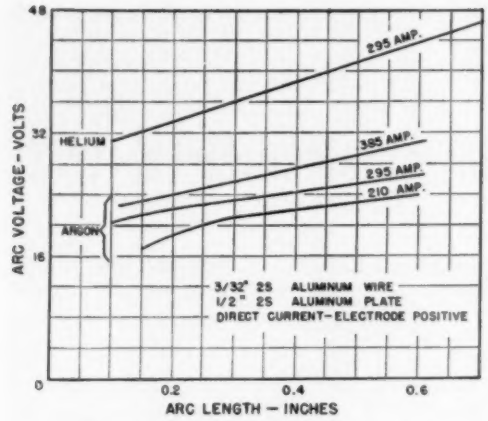

Fig. 2 Influence of arc length on voltage

because the location of the anode spot is indefinite and craters are formed in the plate under some conditions. Images of the arc varied from about 2 to 15 in. in length. Because of continual wire movement and indefiniteness of the arc extremities, the maximum error in reading is estimated to vary from 1% for the longest arc to 6% for the shortest. Voltage was recorded to the nearest tenth of a volt and current to the nearest 5 amp. Recording meters were used having an accuracy of $\frac{1}{2}$ of 1%. Simultaneous voltage and length measurements were made in all cases. Another possible source of error is the variation in voltage drop at the current pickup. It is difficult to estimate the magnitude of this contact drop but its effect on the over-all relationship is probably minor.

Two corrections were applied to the recorded voltage. The electrical resistance was measured from the tip of the wire to the point where the positive terminal of the voltmeter was connected. The voltage drop calculated using this resistance was then subtracted from the measured voltage. The second correction was made for those runs in which the current had drifted from the desired value. To do this the voltage per unit current obtained from the arc volt-ampere characteristic was multiplied by the amount of current drift and added to or subtracted from the recorded voltage.

Because of the aforementioned variations and possibly others unknown, there was considerable scatter in the data. The situation was partially remedied by averaging a large number of readings. Individual points have not been shown on the curves in order to obtain increased clarity.

Results

The results of the tests described above are shown in Figs. 2 to 5. The variation in voltage gradient ob-

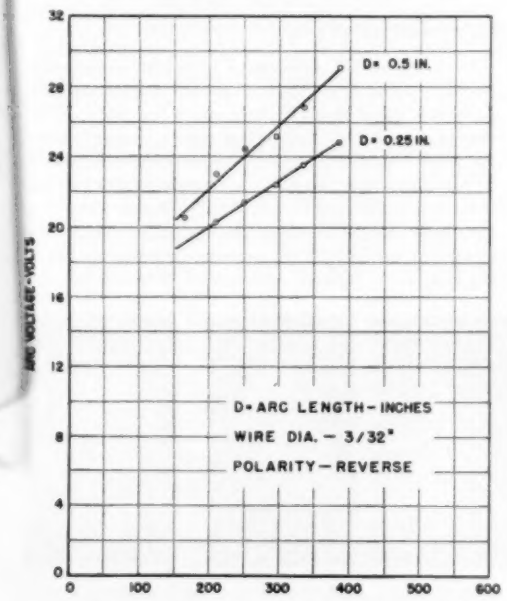

Fig. 3 Volt-ampere characteristic of argon-shielded d.-c. welding arc using aluminum wire and plate

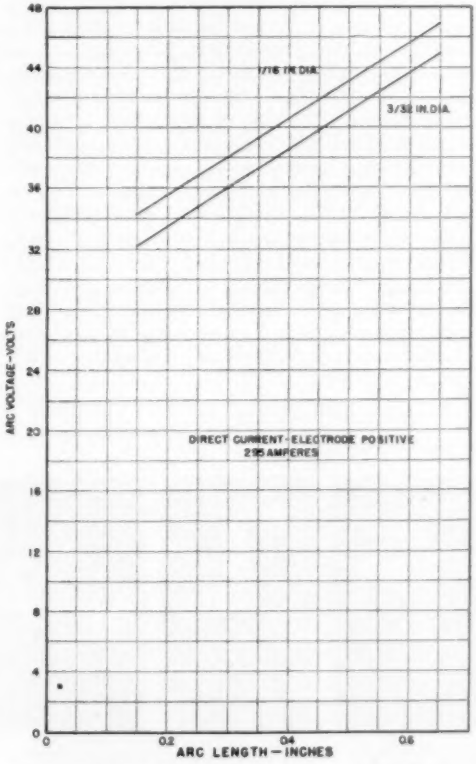

Fig. 4 Effect of diameter of aluminum wire on voltage-arc gap characteristic in helium

tained for the 210 amp. current in Fig. 2 was checked several times. A similar variation has been noted[1] under different conditions. It is probable that the same phenomenon occurs at higher currents for shorter arc lengths but it is difficult to obtain readings at lengths less than 0.1 in. This change in voltage gradient is also apparent with a steel electrode.

The variation in gradient prevents accurate measurement of anode and cathode drop by this method. However, voltage gradients can be measured in the region of the arc in which the gradient remains constant. The results of such measurements are given in Table 1.

Table 1—Voltage Gradients for $^1/_2$-In. Arc Length

Shield gas	*Current, amp.*	*Electrode size and material*	*Gradient, volts/in.*
Argon	210	$^3/_{32}$ in. Al (28)	10
Argon	295	$^3/_{32}$ in. Al (28)	12
Argon	385	$^3/_{32}$ in. Al (28)	17
Argon	210	$^1/_{16}$ in. Al (28)	17
Argon	295	$^1/_{16}$ in. Al (28)	17
Argon	295	$^1/_{16}$ in. 2% Mn Steel	14
Argon	385	$^1/_{16}$ in. 2% Mn Steel	15
Helium	295	$^1/_{16}$ in. Al (28)	26
Helium	295	$^3/_{32}$ in. Al (28)	26

The values in this table are lower than those reported by Suits.[1] This difference can be attributed to the fact that in the arcs listed in the table, metal vapor was present and currents are 20 to 40 times the values previously reported.

From curves like those in Fig. 2, the volt-ampere relations of Fig. 3 were obtained. Particular attention is directed to the positive slope of these curves. It has been previously noted in welding with a nonconsuming tungsten electrode operated negative that a negative slope is produced in the same current range. As expected, the slope for the longer arc is greater. It is interesting to note that if these curves are extended back to the ordinate, they intersect at a common value of 14.9 v. This indicates that the arc plasma acts as a pure resistance in the range examined.

The electrode diameter also affects the voltage-arc length characteristic. Over the short range tested a shift occurs in the curve, Fig. 4, without changing the slope. This may be due to an increase in anode drop without any change in the arc column drop. The arc column does appear to have the same physical structure and dimensions in both cases. For wire sizes much different than those tested, a change in slope is expected to occur.

As mentioned previously the presence of metallic vapor influences the arc characteristic. There appears to be little difference in the effect of steel and aluminum vapor as can be seen from examination of Fig. 5. At 295 amp., the voltage for $^1/_{16}$ in. diameter steel does not differ by more than 0.3 v. from that for $^1/_{16}$ in. diameter aluminum (28) over an arc length varying from 0.2 to 0.65 in.

RADIATION

Spectrograms of arcs of this type show the characteristic line spectra of the shielding gas and metal vapor and the continuous band spectrum of an incandescent solid. The color of the arc depends both upon the shielding gas and metal. The predominant colors noted in the magnified image (21 ×) of the arc are given in Table 2.

Table 2—Predominant Colors of Inert-Gas-Shielded Metal Arcs

Electrode material	*Shield gas*	*Color**
Al(28)	Argon	Orange-red central cone
2% Mn steel	Argon	Blue central cone
5% Al–95% Cu	Argon	Green central cone
Al(28)	Helium	Red (no central cone)

* Outside of central cone there is a gradation of color from red to blue-green.

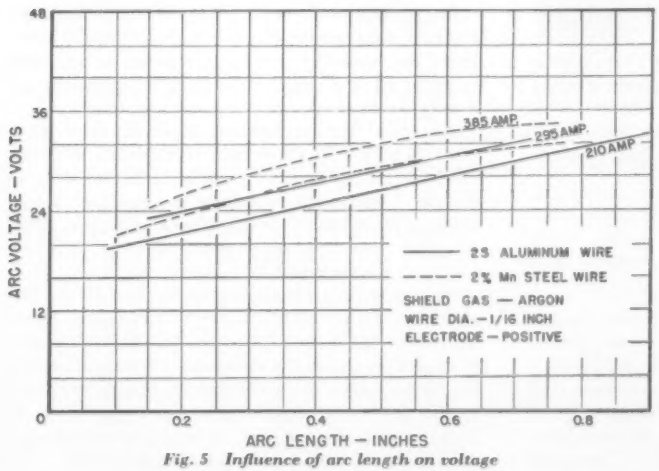

Fig. 5 Influence of arc length on voltage

The emission spectrum for copper shows the strongest visible radiation in the green at wave lengths of 5218, 5153 and 5105 A. units. Similar examination of the iron spectrum shows an abundance of lines throughout the entire visible range. An integration for iron over the visible region by a method similar to that devised by Hardy for absorption lines would show that the predominant color is blue. It is evident, therefore, that the color of the central cones using steel and bronze wire is due to the presence of metal vapor. The dominant radiation from aluminum is in the ultraviolet region with no appreciable amount in the visible range. The color of the arc using aluminum wire is therefore due to the shield gas.

Fig. 6 Argon-shielded arc with 1/16-in. diameter 2% Mn steel electrode

Integration of the argon and helium spectra show that the color is predominantly red or orange-red as is evidenced by the color of the aluminum arcs. The emission spectra for these gases is produced by the very high current of the welding arc. These lines are not observed with the low currents normally used for spectroscopic studies.

An argon shielded arc using 1/16-in. diameter 2% Mn steel wire is shown in Fig. 6. For a longer arc than that shown the outer discharge is brighter and more extensive. Photographs show the outer fringe of the inner cone to be brighter than its center.

A number of photographs were taken at 1/400 sec. with various filters. A red filter (Wratten 29F) produced a large decrease in the brightness of the photographic image showing that the largest portion of the visible light is below 6000 A. units. The central cone still appears brighter than the outer shield and the wire tip is the point of maximum brightness. When infrared film is used with this filter, the central cone image is darker than the outer shield. A green filter (Wratten 58B) brings out the tip of the wire more clearly. This is accentuated further by the use of a blue filter (Wratten 47C5). In other respects the image is the same as that obtained without a filter.

METAL TRANSFER

Burn-Off Rate

The burn-off rate of an electrode wire in an inert-gas-shielded arc increases with current in normal fashion but unexpectedly it decreases as the arc length increases at constant current and this effect is pronounced at high current density. Under these latter conditions the total power increases. However, the gain in power probably is confined to the arc column itself. This extra energy is dissipated in the increased heat losses resulting from the greater arc length and thus cannot produce an increase in burn-off rate. Although the complete mechanism of decrease in burn-off length with arc length increase is not fully understood, it is possible that a reduction in radiation incident on the electrode from the cathode pool may be responsible.

Burn-off rate is not only a function of arc length but is in part determined by the length of wire between the point of current contact and the arc. This effect is only pronounced for high resistivity materials.

Mechanism of Transfer

A distinct change is noticed visually in the character of the metal transfer as the current and feed speed are increased. The transition is rather sudden. The relatively long and erratic intervals between drops change to short regular intervals at the transition zone. Above the transition zone the drops are formed and projected at such high rates that it is impossible to visually detect the presence of individual drops.

High-speed motion pictures, however, show that drops do exist. As the current is increased, the drop size decreases and the number of drops per unit time increases. Eventually a point is reached where more than one drop is present in the arc column at a given time. A large portion of the drops appear spherical and they are fairly uniform in size.

An average drop size can also be determined with the aid of an oscillograph. Peaks on an oscillogram showing arc voltage occur simultaneously with the detachment of a drop from the electrode. Average drop size may be calculated from the number of peaks and the amount of wire consumed in a given time interval. Figure 7 shows the variation of drop size with current, while Fig. 8 shows it as a function of wire feed rate.

The transfer phenomenon is very complex and therefore does not lend itself readily to analysis. With simplifying assumptions, however, the character of metal transfer can be explained at least qualitatively. Previous consideration of this problem with heavily coated stick electrodes led to the conclusion that the primary force resulting in the transfer of metal was the expansion of gas at the electrode tip. This appeared to be borne out by the impossibility of welding overhead with a bare, killed steel electrode.

The analysis for stick electrodes does not apply to the arc under discussion. Consider for a moment transfer below the transition zone. In this case it is apparent that drop size is determined by the surface tension of the material independently of the current density or wire size. The liquid-solid interface moves back up the wire as heat is applied. When sufficient wire is melted, the weight of the liquid and the magnetic pinch effect causes a section adjacent to the liquid-solid interface to neck down. Below the transition point the magnetic effect does not provide sufficient force to cause the separated droplet to be projected across the arc gap, and transfer, therefore, occurs by gravity or other means.

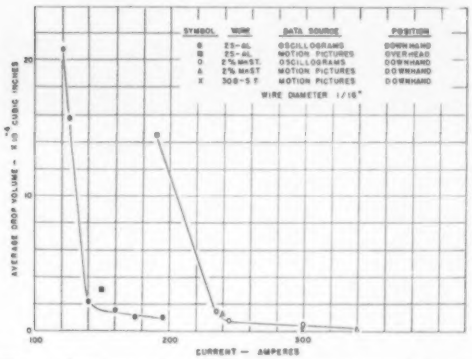

Fig. 7 Influence of welding current on drop volume in the arc

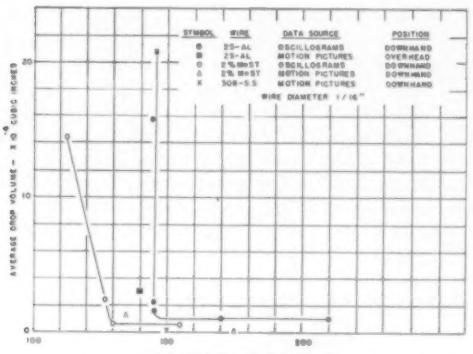

Fig. 8 Influence of wire feed rate on drop volume in the arc

Fig. 9 Overhead projection of a drop from a $^1/_{16}$-in. diameter electrode

Above the transition zone the electro-magnetic pinching force becomes very large. Also, the surface of the wire tip probably reaches the boiling point before enough wire is melted to form a drop as large as that produced below the zone. In consequence, if there were no magnetic forces, the melt would adhere to the wire because of surface tension and transfer would occur principally through vaporization and condensation, gravity, etc. However, the more intense magnetic force present at high current is great enough to pinch off a small size drop and then project it across the interelectrode space. This force is sufficient to project the drop vertically against gravity for a considerable distance. Figure 9 shows such a vertical projection from a $^1/_{16}$-in. diameter aluminum wire at 150 amp. in argon.

Table 3—Chemical Composition of Filler Wire and Deposited metal

Alloy type	*Chemical composition, %*													
	C	*Mn*	*Si*	*S*	*P*	*Ni*	*Cr*	*Mo*	*Ti*	*Pb*	*Sn*	*Al*	*Cu*	*Fe*
Stainless steel, Type 321														
Wire	0.079	1.43	0.58	0.016	0.019	10.52	18.58	...	0.95	...	...	...	...	...
Weld	0.085	1.44	0.63	0.012	0.016	10.52	18.78	...	0.85	...	...	...	...	...
Steel, 1% Mn														
Wire	0.13	1.13	0.16	0.016	0.022	...	...	0.18	...	...	...	...	...	...
Weld	0.09	1.07	0.18	0.017	0.023	...	...	0.19	...	...	...	...	...	...
Aluminum, 438														
Wire	...	0.02	4.57	...	...	...	...	...	...	...	...	95.37	0.05	0.40
Weld	...	0.03	4.45	...	...	...	...	...	...	...	...	95.35	0.10	0.43
Nickel, No. 61														
Wire	0.04	...	0.59	0.005	...	95.08	...	...	2.32	...	...	0.90	...	0.57
Weld	0.04	...	0.62	0.005	...	95.24	...	...	2.36	...	...	0.96	...	0.63
Phos. bronze leaded														
Wire	...	...	...	...	...	...	...	...	...	3.66	5.24	...	Bal.	0.05
Weld	...	...	...	...	...	...	...	...	...	3.57	4.97	...	Bal.	0.04

A particularly interesting characteristic of material transfer through the inert-gas-shielded metal arc is the fact that the chemical composition of the metal which is transferred from the electrode wire to the weld deposit remains the same, i.e., no significant loss of individual elements occurs in transfer. A number of examples which illustrate this finding are listed in Table 3. Data are presented in this table which show wire composition and weld deposit analyses for several widely different type alloys. It is particularly interesting to note that even the extremely reactive elements can be transferred without significant loss. In all other arc-welding processes substantial losses occur in transferring metal from the electrode to the weld deposit. The efficiency of transfer obtained with the inert-gas-shielded metal-arc-welding process affords many advantages resulting from the ability to match the base metal and weld metal chemistry. These advantages include better response to heat treatment in welded alloy steel structures, better corrosion resistance in welded assemblies used in chemical service, elimination of differential expansion in fabricated alloys used at elevated temperatures, etc.

STABILITY

Stability studies on arcs usually involved the relative ease of sustaining the discharge. In low-current welding arcs the drops periodically bridge the gap between the electrode and workpiece causing a short circuit. The arc plasma then deionizes partially or completely during this period. Reignition occurs as the drop breaks contact with the electrode. Unstable arcs will pop out at this time. This phase of stability is principally dependent upon the characteristics of the welding power source rather than the arc. Pop-outs result from slow voltage recovery or too low an inductance in the welding power source. In the inert-gas-shielded arc at high current density the drop size is too small to bridge the electrode gap, therefore, instability due to this cause is not present.

Stiffness

An important aspect of arc stability involves the tendency for the arc to point in the same direction as the wire regardless of the inclination of the plate being welded. The use of high current densities on small wire in open arcs has permitted the observation of this effect which has been called "stiffness." The effect is illustrated in Fig. 10. To produce stiffness, a force field exists to hold the arc in its axial or equilibrium position. The forces result from the motor action produced by arc current flowing through a magnetic field. This magnetic field is set up by current flowing in the electrode. The field takes the form of rings around the arc concentric with the wire. By Ampere's law, each element of this wire produces a magnetizing force at any given point in the vicinity of the arc. The magnitude of this force is given by the following equation:

Fig. 10 Illustration of arc stiffness

$$dH = \frac{I \cos \theta}{S^2} \, dA \, dz$$

where

I = current density in the wire.
θ = angle of inclination of the point with the plane normal to the element.
dz = incremental length of the element.
S = distance from point to element.
dA = incremental area of cross section of element.

This force is directed according to the familiar right-hand rule: i.e., in the plane normal to the axis of the element through the point in question and perpendicular to the line adjoining the point and the element. It can be seen that the direction of this magnetizing force will vary with the position of the element in the wire. The total magnetizing force at any point can be determined by a summation of the tangential components contributed by all elements in the wire. This involves integration through the cross section of the wire and along its length. This integration yields the following equation:

$$H = \frac{I}{R}\left[\frac{Rr}{R^2 + r^2}\left(1 - \frac{l}{\sqrt{R^2 + r^2 + l^2}}\right) + \left(\frac{Rr}{R^2 + r^2}\right)^3 \left(1 - \frac{l}{\sqrt{R^2 + r^2 + l^2}}\right) + \ldots\right]$$

where

H = magnetizing force, oersteds.
I = current, abamperes.
R = radius of wire, cm.
l = axial distance to point, cm.
r = radial distance to point, cm.

By symmetry, it can be proved that the summation of radial components vanishes. The magnetizing force therefore produces a magnetic field which acts on the arc so as to force it into alignment with the wire. The aligning force increases as the square of the current and is greater for small diameter wire. A plot of the restoring force field pattern for $^1/_{16}$ and $^1/_8$-in. diameter electrodes at currents of 100 and 200 amp. is shown in Fig. 11.

The lines are formed from the locus of points at which

restoring force is constant. Multiples of five dynes per millimeter of arc length were selected for plotting loci on the left side of the patterns. A logarithmic plot was selected for the right side of the pattern. Loci were drawn for 5, 10, 20, 40, 80, 160, etc., dynes per millimeter of arc length.

From the density of lines on the left side of the plot, it can be seen that the portion of the arc directly under the wire is stiffer than the portions further removed. It can also be seen that higher currents with smaller diameter electrodes produce stiffer arcs.

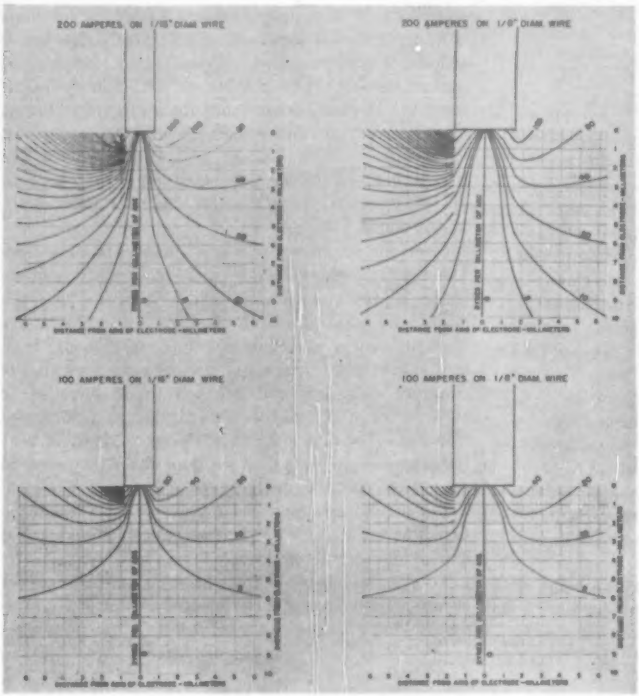

Fig. 11 Magnetic restoring-force patterns

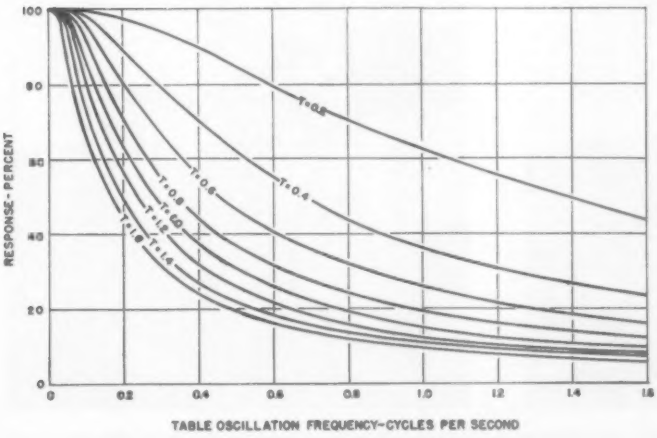

Fig. 12 Theoretical wire response for a self-regulating arc

Self-Regulation of the Arc

Mathematical Analysis. The fact that constant-speed wire feeders are capable of holding a steady arc with approximately constant-current power sources indicates that some sort of self-regulating control is present. The decrease in burn-off rate with increase in arc length at constant current provides the source of regulating ability. This ability enables the tip of the electrode to follow movements of the work relative to the electrode holder. The ability of the electrode to follow changes in contour can be evaluated by studying the response of the wire tip to oscillations of various frequencies imposed upon the plate being welded.

Mathematical analysis can also be used to predict this response. To do this, an assumption is necessary concerning the mode of regulation. It was assumed that the rate of correction of the tip of the welding wire is proportional to the displacement from its equilibrium position. The equilibrium position is that position assumed by the electrode tip for normal arc length. This assumption appears reasonable for this system. Expressed mathematically:

$$\frac{dx}{dt} + \frac{1}{T}x = 0$$

where $1/T$ is the proportionality constant and x is the displacement from the equilibrium position.

When the plate is subjected to a sine wave oscillation of amplitude A and frequency f, the equation of motion is

$$\frac{dx}{dt} + \frac{1}{T}(x - A \sin 2\pi ft) = 0$$

The solution to this equation is

$$R\frac{1}{\sqrt{1 + 4\pi^2 f^2 T^2}} \sin(2\pi ft - \arctan 2\pi fT)$$

where R is fractional response (ratio of wire movement to plate move-

ment). It is seen that the frequency response curve is dependent on a single parameter, T, the time constant.

If the initial assumptions are correct, the band-pass curve obtained from actual test will belong to one of the family of curves shown in Fig. 12 and expressed by the equation

$$R = \frac{1}{\sqrt{1 + 4\pi^2 f^2 T^2}}$$

Each curve corresponds to a different value of the time constant.

Method. Figures 13 and 14 show the equipment used to oscillate the workpiece. The former is a close-up of the oscillating table. The top plate moves vertically on the large cylindrical slide. It is powered by a variable-speed motor through the gears, crank and connecting rod. This method of drive results in a sinusoidal variation in plate position. The amplitude of this movement can be varied, but $^1/_4$ in. was used throughout these tests. Oscillation frequency was measured by recording the occurrence of a particular crank position on a moving chart of known travel speed. It could be varied from 0.2 to 1.6 cycles per second.

In Fig. 14 the general arrangement of apparatus is shown. The table is mounted on a carriage. Above the table is a laboratory model of a welding nozzle. Adjacent to the table and nozzle is a pinhole camera. The camera has a ground-glass screen upon which the arc image can be viewed. The relative movements of table and wire tip can be determined from a scale drawn on the screen.

It was sometimes difficult to determine the point of the table directly under the wire when making the measurements. The difficulty was overcome by placing an acetylene flame on the table surface directly under the wire and measuring the excursion of its image on the ground glass.

Recording meters were used to measure voltage and power. Current was measured with an indicating meter. Gas flow was determined with a standard flowmeter.

For each frequency of table oscillation the ratio of the amplitude of wire movement to amplitude of plate movement was determined. This ratio times 100 is called per cent response. These values were plotted against the frequency of table oscillation in cycles per second. The curves were then drawn in the following manner. Values were substituted for the parameters in the theoretical response equations. The values were adjusted until the theoretical curves obtained using these equations fitted the experimentally determined points.

Since the frequency response curves completely define the transient behavior of the control system, response to any variation in work position can be determined by mathematical analysis. An alternative method involves direct measurement of response from motion pictures taken while welding over a number of contours. The contours selected would have to be those most likely to be encountered in commercial welding. The first method results in economy of testing time. Flat plates rather than specially prepared projection samples can be used. Moreover this technique is more informative since responses to irregularities differing in shape or dimensions from those selected can be precisely determined.

Four variations of the work position were selected for study. The names of those selected as well as diagrams which illustrate them are listed below.

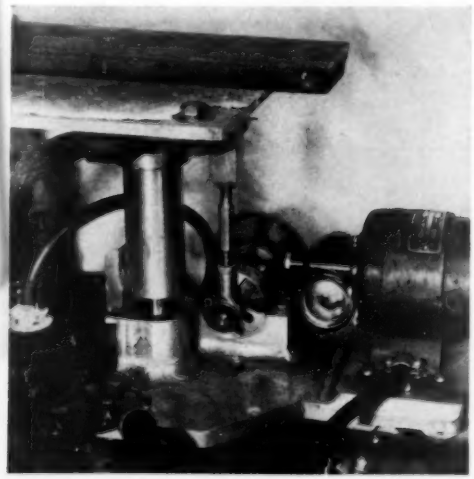

Fig. 13 Oscillating table for studying self-regulation of the arc

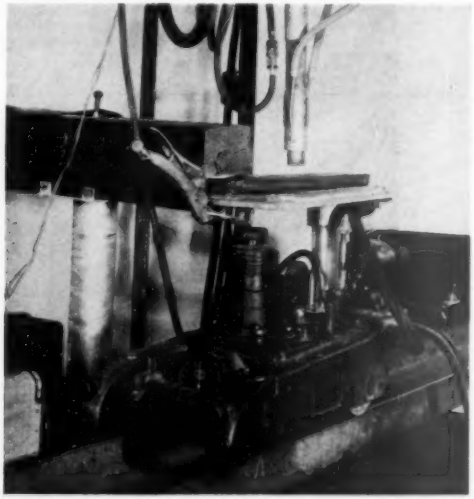

Fig. 14 Arrangement of apparatus for studying self-regulation of the arc

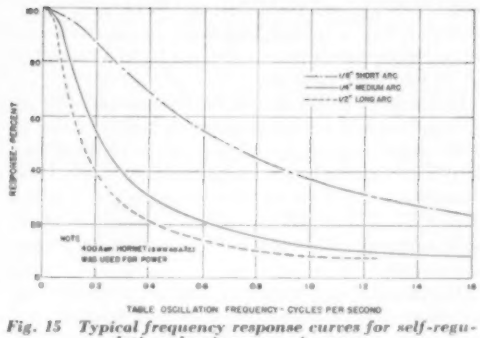

Fig. 15 Typical frequency response curves for self-regulating aluminum arcs in argon

(1) Step

(2) Ramp

(3) Triangular, Projection

(4) Sine Projection

The sine projection would represent the type of discontinuity encountered when welding across and at right angles to another bead. The triangular projection and ramp would represent welding up or down the surface of inclined plates. Although the abrupt step would not normally be encountered in welding, it was

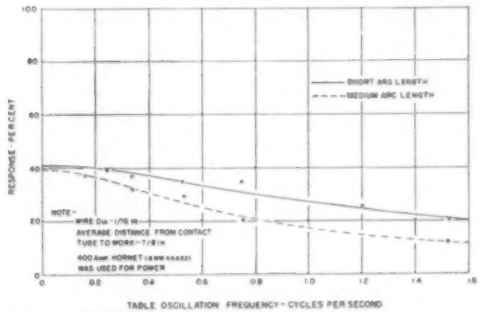
RESPONSE - PERCENT
TABLE OSCILLATION FREQUENCY - CYCLES PER SECOND
NOTE -
AVERAGE DISTANCE FROM CONTACT
TUBE TO WORK - 7/8 in
WAS USED FOR POWER

Fig. 16 Frequency response for self-regulating arcs in argon using stainless steel wire

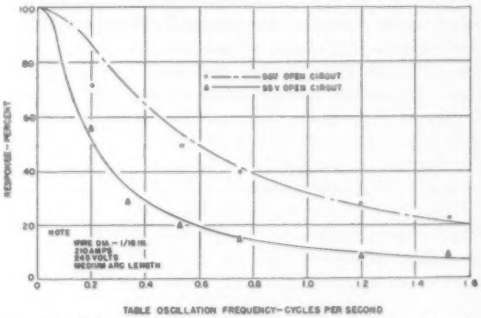

Fig. 17 Effect of power source on self-regulating aluminum arcs in argon

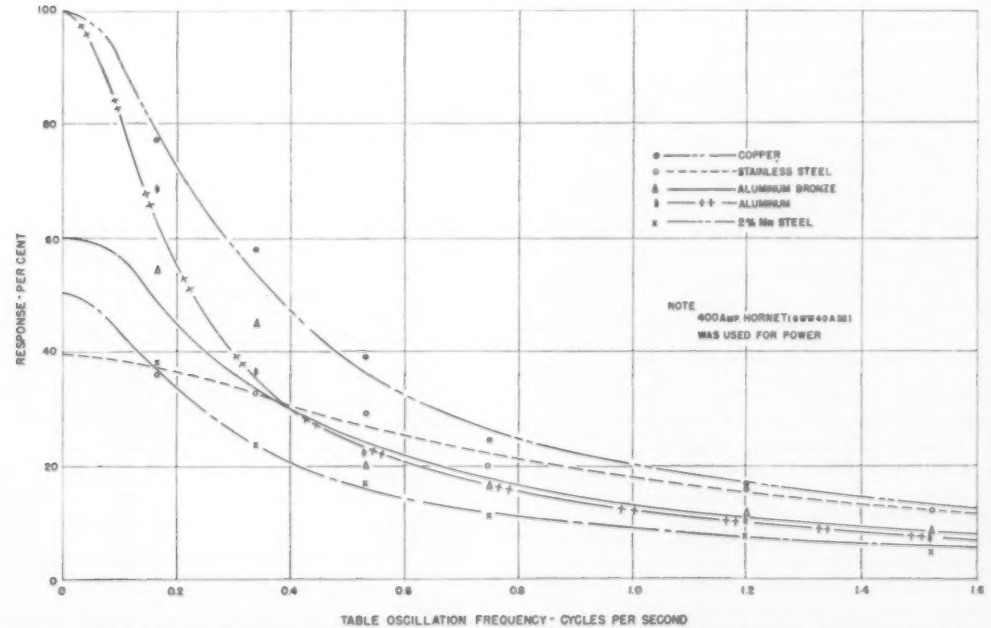

Fig. 18 Variation of frequency response with the type of wire for self-regulating argon arcs of average length

included because it tends to accentuate small differences in control characteristics.

All basic irregularities were set at $^1/_8$ in. in height. Heights greater than $^1/_4$ in. would necessitate manual adjustment of the nozzle to maintain adequate shielding. The ramp is 1 in. long, the triangle projection 2 in. long and the sine projection $^1/_2$ in. long. It is believed that welding over these contours at a speed of 12 in. per minute represents as severe a condition as would likely be encountered in practice.

Results. Some exploratory tests were run which indicated that variation of plate thickness and welding speed had a negligible effect upon regulation. A number of tests were then run using several materials and wire sizes.

Analysis of data on aluminum revealed that regulating characteristics were not materially affected by current density or wire size within the range of wire diameter and current used. Therefore, typical curves for aluminum were drawn in Fig. 15 for three arc lengths. It is evident that arc length is the major factor in affecting the frequency response.

The effect of arc length is again noted with stainless steel in Fig. 16. A major difference is that the maximum response obtained is 40%. The same assumptions were made in arriving at theoretical responses for stainless steel as were made for aluminum. It was found, however, when an attempt was made to fit curves to observed data that the equations had to be multiplied by a fixed constant between zero and one. This was due to the fact that resistance heating in the wire projecting from the contact shoe is not negligible in these alloys. A revision of the theoretical curves based upon the assumption that burn-off rate is not only proportional to arc length but to terminal portion as well, justified this procedure.

The revised equation representing these curves is

$$R = \frac{A}{\sqrt{1 + 4\pi^2 f^2 T^2}}$$

Variations in the curves are due to variations of the parameters A and T. It can be proved that the change of burn-off rate with arc length is A/T in. per second per inch of arc length and the change with terminal portion is $(1-A)/T$ in. per second per inch of terminal portion.

Since the welding generator characteristics exert an influence on self-regulation, a test was run with two different volt-ampere characteristics. The results are shown in Fig. 17. The frequency response was affected to the same degree as it would be by a change in arc length from $^1/_8$ to $^1/_4$ in.

Figure 18 compares the regulation obtained with an average length of arc for all materials tested. Because of the large variation in resistance of the terminal portion, it is expected that the parameter $(1 - A)/T$ should vary widely for the different materials. On the other hand, A/T would be expected to remain substantially constant. That this is so can be seen by examination of Table 4.

The data for steel were very difficult to obtain with an average length arc. Unless a long arc was held, the upward movement of the table resulted in a complete change of arc characteristics. The normal arc changed to a much shorter arc that was smokey and had a

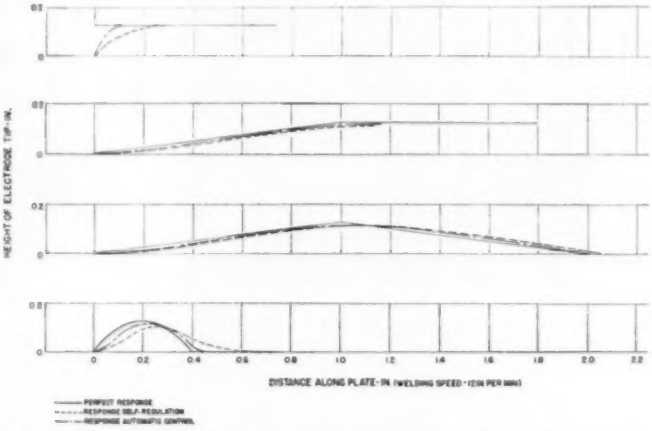

Fig. 19 Comparison of automatic and self-regulating arc control for $^1/_{16}$-in. aluminum wire in argon using a short arc length

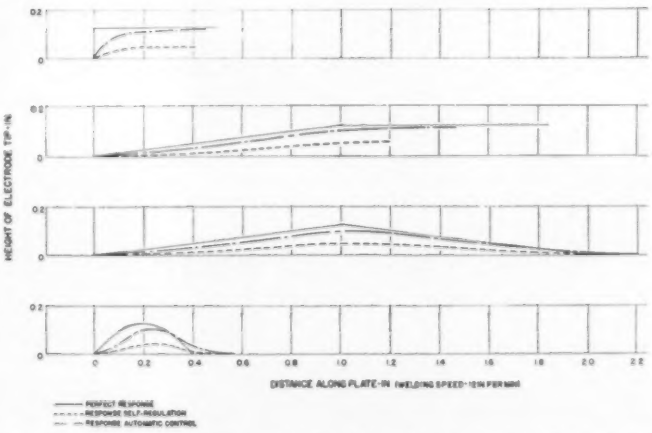

Fig. 20 Comparison of automatic and self-regulating arc control for $^1/_{16}$-in. stainless steel wire in argon using a medium arc length

Table 4—Comparison of Response Coefficients with Electrical Resistivity

Electrode material	*Resistivity, ohms/circ. mil. ft. at 32° F.*	$(1 - A)/T$	A/T
Copper	10.4	0	1.29
2S aluminum	17.6	0	0.806
2% Mn steel	60	0.556	0.556
8% Al-92% Cu	210	0.572	0.859
Stainless Steel, Type 316	440	1.83	0.836

square-ended electrode. It was further characterized by an unexpected increase in arc voltage and the appearance of spatter. An exceptionally long arc had to be used in order to overcome this difficulty. This resulted in an increase of the time constant T. If an average arc could have been held, the values of A/T and $(1 - A)/T$ would have changed so as to provide a better correlation with the other values in Table 5.

Figures 19 and 20 show the control to be expected for the four variations in work position using stainless steel and aluminum. A similar analysis was made for a welding unit employing automatic voltage control and the expected control plotted for comparison. There appears to be little difference in the case of aluminum, but the difference for stainless steel is appreciable.

SUMMARY

In reviewing the characteristics presented it can be seen that several are peculiar to inert-gas-shielded metal arcs provided high current density is employed. The most interesting of these are as follows:

1. Large positive slope of the volt-ampere characteristic.
2. Stiffness of the arc column.
3. Sudden transition in drop size with increase in wire feed speed.

The latter characteristic is the most striking and significant. Above the transition zone the arc has greater commercial application. In this range, metal transfer is produced by large electromagnetic forces which are capable of projecting the small droplets of metal in an axial direction for a considerable distance. Moreover, the smaller drops have less disrupting effect on the inert gas shield which results in negligible alloy loss in transferring metal through the arc. The increased stiffness which occurs at high current densities permits excellent control of the weld pool which in turn results in the ability to weld in all positions.

ACKNOWLEDGMENT

The authors are indebted to J. W. Cunningham and R. Burnham of the Air Reduction Research Labs. for their assistance in obtaining the data.

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Pressure Welding

Part I—History. Part II—Cold-Pressure Welding

History with a brief review of principal patents and literature. Critical part of cold-welding processes is cleaning of surfaces. Physical properties are indicated, also structures, equipment and applications

by F. C. Kelley

Part I—History

THE art of "pressure," or "solid phase," welding is old. As early as 3000 B.C. the Egyptians heated iron ore in a charcoal fire to reduce it to sponge iron; the particles were then welded together by hammering.[1] In 1829, Wallaston produced sponge platinum and welded it together by cold pressing, sintering and then hammering while the metal was hot.[2]

In 1853, a U. S. Patent was granted to Henry Hunt on a method of sealing a tin can to make it vacuum-tight.[3] A small, short tube of any pliable metal (preferably block tin or lead) was secured to the head of a tin can by an air-tight joint. After the can was filled and its cover soldered in place, it was evacuated through the tube. The walls of the tube were then "mashed" or forced together by means of a pincers or other suitable tool; the resulting joint was an air-tight cold weld. The upper part of the tube was cut off and the end of the remaining part soldered over to insure that the seal would remain tight.

Thomas J. McTighe was granted a U. S. Patent in 1881 on a method of making lead cable.[4] Grooved lead sheets, with insulated wire placed in their grooves, were passed through corrugated or grooved rolls under heavy pressure, with the result that the strips were welded together. To facilitate production, McTighe preferred to manufacture the grooved strips and, when they emerged from the press or rolls, lead the still warm and unoxidized metal directly into the welding rolls.

A U. S. Patent was granted to James H. Bevington in 1891, on a method of closing or joining tubes.[5] The process called for pushing the ends of the tubes into a die revolving at a rate sufficient to heat the metal through frictional contact, thereby softening the metal and causing it to weld. A variation in the basic method provided for the tube to revolve while the die remained fixed; the tube and die could also be revolved in opposite directions.

Alexander Dick was granted a U. S. Patent in 1903, on a process for uniting metals.[6] His patent covered a method for welding copper, copper alloys, aluminum and similar materials which previously had been joined by a low-temperature solder or alloy, thereby disallowing a subsequent heating operation. The wire, sheet or rod to be welded was first heated; then the oxidized ends or surfaces were removed by a saw or wheel. Immediately, the clean surfaces were brought together under pressure and then forged, or a non-oxidizing atmosphere could be used to prevent oxidation of the freshly cut surfaces.

A U. S. Patent granted to William Schieber described a method of welding copper, nickel and copper or nickel alloys.[7] The parts to be welded are heated to a temperature below the melting point in an atmosphere of hydrogen and oxygen and are then united by hammering or pressing. The composition of the atmosphere used is such that the proportion of hydrogen to oxygen exceeds the ratio 2H:O.

A. U. S. Patent granted to John L. Fate in 1921 covered a method for sealing a vacuum jacket.[8] After the jacket was exhausted, the walls of the exhaust tube were flattened using a specially designed pincers. A current was then passed through the pincers to produce a weld.

Percy E. Hunter received a U. S. Patent in 1925 on an apparatus for welding metal.[9] This welding machine was made to join specially designed joints under continuous pressure. One die was stationary and the other movable; the parts were heated and pressure applied by hydraulic means.

"Pressure Welding of Low-Carbon Steels with Theoretical Considerations of Mechanisms of Such Welding," published in 1932 by C. R. Austin and W. S. Jeffries,[10] describes the pressure welding of steels in air, hydrogen and vacuum, at temperatures ranging from 1100 to 1500° C. The reported results varied because of oxide films, variations in surface alignment and differences in the characteristics of the surfaces welded. Smooth

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surfaces gave the best results; oxidized surfaces gave poor welds or no welds at all. Likewise, the best results were obtained in hydrogen atmospheres. Impact welds gave no better results than pressure welds.

Examinations of fractures under a binocular microscope and of polished specimens, both etched and unetched, revealed welded and unwelded areas, oxide inclusions and variations in grain orientation on either side of the joint.

Welds made in air always broke at least partly in the junction line of the weld. When perfectly flat surfaces in perfect alignment were rotated, the strength of the joints were markedly improved.

In "Some Fundamentals of Spot Welding, Especially of Light Alloys," published by Raymond H. Holbrock[11] in 1935, it was shown that aluminum and its alloys could be welded by heating, between the electrodes of a spot-welding machine, to a temperature below the melting point and applying pressure.

W. D. Jones, in his book *Powder Metallurgy*[12] published in 1937, wrote as follows:

"Two metal surfaces, if sufficiently clean and sufficiently flat, will weld or sinter together without the use of high temperatures. The conditions of commercial welding or sintering as far as temperature is concerned are purely a question of plasticity. Naturally, a plastic metal under pressure will have a larger number of true contacts than a rigid one. The effect of increasing temperature is merely to increase the plasticity of the metal concerned."

The book *Silver in Industry*, edited by Lawrence Addicks and published in 1940,[13] contains the following:

"*Temperature*

"Since heating (short of fusion) increases plasticity, temperature becomes an important factor in welding by promoting intimacy of contact. Elevated temperature, therefore, promotes pressure welding, but is not an essential condition.

"*Pressure*

"Application of pressure supplements heating and plasticity in bringing about the required intimacy of contact . . . if the surfaces are ground flat to a degree possible with optical glass, both pressure and heat may disappear as factors.

"*Time*

"Time is an important factor in producing a strong bond in pressure welding. It is not an essential factor as instantaneous welds may be made under favorable conditions."

In 1941, Oskar Renner was granted a U. S. Patent[14] on a method for welding metal (steel) rails under pressure. He heated clean, polished, flat surfaces under pressures of 300 to 2000 psi., at temperatures of 1000 to 1300° C. for three minutes, using oxygen and fuel gas or high-frequency induction heating, to obtain welds.

In 1944, A. B. Kinzel, lecturing on the subject "Solid Phase Welding,"[15] claimed that the solid-phase welding of structural members was relatively new. He said that the complete elimination of the interface in steel, as determined by the microscope, is the best scientific criterion of the worth of a pressure weld. He also claimed that, in the solid-phase welding of ferrous materials, 1050° C. is the minimum temperature which will diffuse the interface film in the short time available in pressure welding.

The Linde Air Products Co., with which Kinzel is associated, holds patents on pressure welding with gas heating. One license is that of the Menasco Co., whose process for butt joints in bars and tubes is called "Uniwelding." It is reported that this company is currently producing about 30% of the landing gear for U. S. military aircraft.[23]

A paper, titled "The Pressure Weldability of Iron" and written by Hans Essler[16] in 1946, deals with the welding of three different grades of electrolytic iron. Pressure was applied after the irons had been heated in a vacuum. Highly polished surfaces gave better results than rough ones, and fine-grain structures showed the best results and highest weldability. At 900° C. the grains grew across the interface; weldability increased with temperature and, the higher the temperature, the less was the amount of pressure required to produce a weld. Pressures of 0.64, 1.27 and 2.23 tons per square inch were used; at the melting point, zero pressure was required to obtain a weld. It was found that a carbon content of 0.4 to 0.5 was the maximum for good weldability.

A paper written by H. Herrmann[17] during the war and obtained in Germany by an investigating team is titled "Pressure Welding" and deals with the manufacture of a light-alloy charge-cooler element used with the Jumo 211-F engine in the Junkers 88 aircraft. This charge-cooler was hot-pressure welded from an aluminum alloy known as "Pantal," having the following composition:

Magnesium	0.79
Silicon	1.10
Manganese	0.85
Iron	0.39
Titanium	0.02
Copper	0.13
Zinc	0.15
Nickel	0.05
Aluminum	Balance

Cleaning was accomplished by dipping the material for one-half minute in 15–20% nitric acid at room temperature, rinsing in water, dipping in 15–20% sodium hydroxide at a temperature not over 50 or 60° C., rinsing in water, dipping again in 15–20% nitric acid and rinsing again in water. The material was then dried in an electrically heated furnace and the side to be welded was wire brushed.

Any fingerprints left on the sheet produced a faulty weld and could be removed only by wire brushing or grinding. The least expensive procedure for use on a large scale proved to be etching the sheet before the last pass through the rolling mill, and finishing with

polished rolls. The sheet was then wire brushed at the fabricating works not more than one to one and one-half hours before pressure welding.

Two sheets of Pantal, each 0.4 mm. thick, were pressure welded together in elaborate dies heated to 420–480° C., depending upon the alloy used. The die steel was the following composition:

Carbon	1.8 to 2.0
Silicon	0.5
Chromium	12.3
Vanadium	0.15
Iron	Balance

A reduction of about 50% and a pressure of about 3.2 tons per square inch was required for welding the Pantal alloy.

Prevention of sticking required that the dies be machined and ground. Surfaces which were too smooth caused sticking; even though the dies were coated with a mixture of talc and saltpeter before the initial heating, the first six to ten parts stuck fast to the dies and had to be torn off. Sticking became less frequent as the tools roughened, and then stopped completely.

Every second sheet was smeared thinly with a mixture of talc and saltpeter in water, and washed immediately after welding because of the danger of corrosion. The saltpeter melts at 300° C., causing slight dampness of the die; enough salt and talc adhered to the welding tooth after welding to permit one more article to be welded without applying additional lubricant. The formula for the lubricant was as follows:

French chalk, kg	1.6
Water, kg	3.5
Sodium nitrate, kg	0.8
Potassium nitrate, kg	0.3
Potassium chromate, kg	0.015

"A Few Observations on Solid Phase Bonding" is the title of a paper by George Durst[18] which appeared in 1947. The author claimed that the pressure welding of aluminum could be accomplished only under a shear stress because of the oxide film on the metal surface. He described the welding of copper to copper and nickel to nickel in a vacuum by dropping a pointed rod on a flat plate by the use of magnets. The absorbed films were removed in the vacuum and no heat was required. The following paragraph is quoted from the above paper:

"Aluminum can be pressure welded satisfactorily only under shear stress, independent of welding temperature, due to the extremely tough though invisible oxide film which, fortunately, can easily be broken up by rolling, forging, or upsetting. Pressing without any lateral movement will not destroy it sufficiently."

"Pressure Welding of Light Alloys Without Fusion," by R. F. Tylecote,[19] appeared in 1945. Tylecote showed that aluminum and aluminum alloys could be welded under pressure at different temperatures below the melting point. A certain minimum deformation was necessary to obtain a satisfactory weld at each temperature, and the material had to be pickled and wire brushed before welding. This method of cleaning permitted welds to be made by heating the material and deforming it only 20%. Tylecote also stated that welding could probably be accomplished at temperatures down to room temperature if higher pressures could be used.

In 1947, a U. S. Patent was granted to Garner and Bricker[20] on a method of cold welding exhaust tubes of materials such as copper, brass, etc. Their method used two round, parallel jaws of a metal harder than the exhaust tubes, which were pressed against opposite sides of the tubes until the material began to flow between the rods, and the line of demarcation between the two walls disappeared. Radial flanges of an envelope shell could be sealed by welding between two hardened steel rings, or the seal could be made by pressing in sections or with high-pressure rolls.

A U. S. Patent granted to Richard S. Reynolds,[21] in 1949 describes a method for cladding steel with aluminum. The steel is electroplated with a 0.0001-in. thickness of iron on one or both sides. Aluminum foil is then applied to the plated surface and hot-rolled at 800 to 900° F.

"Cold Pressure Welding" is the title of a booklet issued by the British General Electric Co., Ltd., and dated November 1948.[22] This booklet describes the welding of aluminum to aluminum, aluminum alloys, cadmium to cadmium, lead to lead, copper to copper, nickel to nickel, zinc to zinc and silver to silver. The method of cleaning (wire brushing) before welding and the tools used are described; a table which reveals the amount of deformation required to cold weld each of the various metals is included.

A study of the voluminous bibliography abstracted above reveals that most early pressure welding was done by heating. It is also apparent that some recognized that welding could be done cold if higher pressures were used. It is probable that the recent commercial applications of cold welding derive, in part, from observations made in Germany. After the war was over, British scientific personnel had an opportunity to investigate at first hand the German accomplishments, especially in the hot-welding field.

See "Bibliography" at end of Part II.

Part II—Cold-Pressure Welding

THE PROCESS

Many like metals, as well as dissimilar ones, have been cold welded by each of several methods. Pressure may be applied by two punches or tapered rolls held in perfect alignment, by a shoulder punch on one side of the material and a flat plate or anvil on the other or by a single tapered roll and a flat-surfaced roll. Punches

with shoulders have been used to control the amount of punch penetration into the material and flatten the deformed sheets at the same time.

The most critical part of the cold-welding process is the cleaning of the materials before welding to remove the oxidized layer on the surface to be welded. In the case of aluminum, chemical cleaning is not satisfactory. Even after etching, thin layers which are produced on the surface by the chemical reactions must be removed by wire brushing. Wire-brushed aluminum does not have to be welded immediately; it can be left standing for several hours and still give good welds. A combination of pickling and wire brushing has been found to be satisfactory for various metals. Grit blasting followed by wire brushing has also given good results.

One procedure may include the following steps. After the materials have been wire brushed, the two cleaned surfaces are placed together between the punches shown in Fig. 1. The punch assembly is then placed in a hydraulic press (as in Fig. 2) and pressure is applied. As shown in Fig. 1, the punches are wedge-shaped, the angle between the wide faces being approximately 60°. When pressure is applied to the assembly, the punches penetrate the material, causing it to flow laterally.

Figure 3 shows the amount of deformation which occurs when aluminum is welded with punches having no shoulders. The amount of deformation required to produce a satisfactory weld is quite critical and varies with different metals. The deformation for aluminum is about 70%; thus the thickness of the material left in the weld is only 30% of the original joint thickness. The British call this number, i.e., the percentage of material left in the weld, the "Figure of Merit." (See "Figures of Merit" for various metals in Table 1.)

Fig. 1 Punch assembly for cold-pressure welding

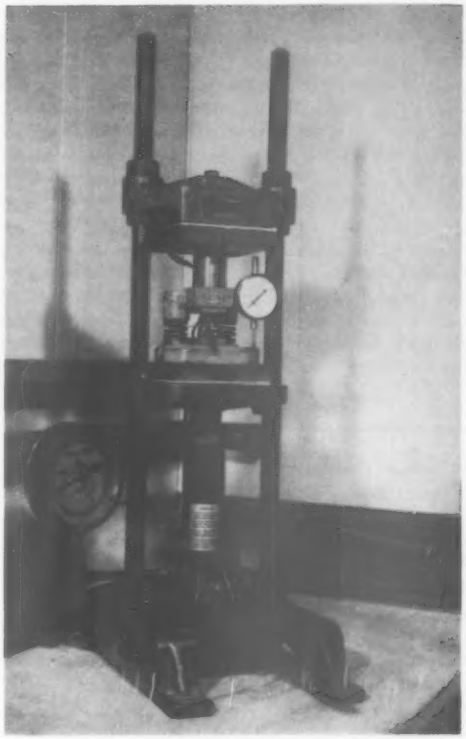

Fig. 2 Hydraulic Press

For example, if two .050 inch sheets of aluminum are cold welded, where t is the thickness of the finished weld and T is twice the original thickness of the material, then:

$$\frac{t}{T} \times 100 \quad \text{or} \quad \frac{30}{100} \times 100 = 30$$

Therefore, 30 is the correct percentage of original thickness to leave in the gap between the plungers to produce a satisfactory weld. This is the "Figure of Merit" for aluminum. The dial gage attached to the punch assembly (shown clearly in Fig. 1) can then be set at .030 inch with the punch faces together. The two .050 inch sheets are then inserted between the punches and pressure is applied until the dial indicator registers 0 in. This leaves .030 inch of metal in the weld.

Fig. 3 Cold-pressure weld between two sheets; deformation when punches without shoulders are used

The speed with which the weld is made seems to make little difference in the amount of deformation required or in the strength of the welds. The essential part of the cold-welding process is that the clean surfaces of the sheets to be joined be brought together during deformation so that the atoms of one surface are pushed into the atom structure of the other and the interface between the two is eliminated completely. This is possible with the more ductile metals; they are forced into intimate contact and, as they flow laterally from under the punches, the atoms of the two surfaces intermingle and a weld is formed. Friction between the flowing metal surfaces probably results in seizure and aids in welding. Since welds can be made by applying pressure very slowly, there is little evidence that heat of deformation plays much of a part in the cold welding of aluminum. The chief function of heat in pressure welding is to increase the ductility of the metals, allowing them to be placed into more intimate contact at lower pressures, as well as to increase the mobility of the atoms. Considerable cold work will exist in a cold weld and this may be decreased by the annealing action of heat, as in a hot weld.

When two strips of metal, cold welded together, are pulled in tension, putting the joint in shear, failure occurs at the periphery of the necked-down section of the strip. The welded area is left in relief on one strip; a hole appears in the other where shearing took place. It is difficult to measure the area of the sheared section; so the breaking load (in pounds) is the only accurate measure available to determine the strength of the weld.

Table 1—Results of Tests on the Cold Welding of Various Metals

Metals welded	*Punch width, in.**	*Figure of Merit*	*Welding load, lb.*	*Welds per specimen*	*Average breaking load, lb.†*
		Similar metals			
Aluminum to aluminum	1/16	30	1,250	1	211
	1/16	30	1,250	2	380
	1/16	30	1,250	3	434
Lead to lead	1/16	30	250	1	29
	1/16	30	250	2	72
Cadmium to cadmium	1/16	16	1,250	2	149
Tin to tin	1/16	16	350	2	104
Zinc to zinc	1/16	16	3,100	2	184
	1/16	12	3,100	2	253
Brass to brass					
Annealed	1/32	13	...	2	454
Cold-rolled	1/32	16	7,500	2	465
Copper to copper	1/16	11	3,200	1	327
	1/16	11	3,200	2	609
	1/16	11	3,200	3	782
Iron to iron	1/32	8	5,500	2	503
	1/16	8	5,500	2	609
18–8 to 18–8	1/32	6	8,500	2	289
Nickel to nickel	1/32	6	5,750	2	553
		Dissimilar metals			
Aluminum to lead	1/16 on Al 1/8 on Pb	30	1,000	2	41
Aluminum to brass	1/16	30	2,400	2	191
Aluminum to copper	1/32 on Cu 1/16 on Al	16	...	2	171
Aluminum to iron	1/16 on Al 1/32 on Fe	12	3,800	2	200
Aluminum to nickel	1/32 on Ni 1/16 on Al	8	5,000	2	148
Lead to tin	1/16	30	250	2	47
Cadmium to tin	1/16	30	450	2	90
Cadmium to lead	1/8 on Pb 1/16 on Cd	24	300	2	40
Zinc to aluminum	1/16	30	5,300	2	246
Zinc to brass	1/16	16	4,700	2	385
Zinc to copper	1/16	16	4,500	2	444
Zinc to iron	1/16	12	5,300	2	274
Brass to copper	1/32	16	6,500	2	421
Brass to iron	1/16	12	12,000	2	617
Brass to 18–8	1/32 on 18–8 1/16 on brass	11	7,100	2	571
Brass to nickel	1/32 on Ni 1/16 on brass	12	7,000	2	422
Copper to iron	1/16	16	7,000	2	451
Copper to nickel	1/16	11	4,375	2	398
Copper to 18–8	1/16 on Cu 1/32 on 18–8	11	7,100	2	592
Iron to nickel	1/16	12	11,000	2	709
Iron to 18–8	1/32	6	7,000	2	445
Nickel to 18–8	1/32	6	7,300	2	595

* Length of all punches is 0.325 in.
† Failed by tearing at periphery of necked-down section.

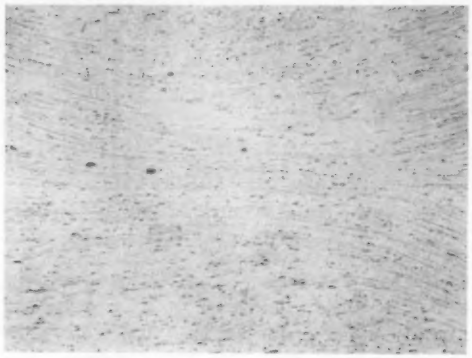

Fig. 4 Aluminum to aluminum weld

It is possible to make several welds on two strips of metal and cause a break across the entire strip, but in this case the path of rupture is always through one or more of the necked-down sections.

PHYSICAL PROPERTIES OF VARIOUS COLD-WELDED METALS

Table 1 is a tabulation listing metal combinations which were cold welded, the number of welds per specimen, sizes of the punches used, the "Figure of Merit," the average breaking load in pounds and the pressure required to make a weld with the punches used.

It should be noted that, when welding aluminum to aluminum, two or three welds in a single specimen do not produce two or three times the strength of a single weld. This is a result of the deformation which the metal undergoes when more than one weld is made. That is, each weld made on a small test specimen increased the deformation and may weaken the welds already made due to the additional stress. All of the test specimens were flattened after welding: this probably introduced additional stress. When the specimens are pulled in tension, one weld may be subjected to a greater stress than the others and hence yield first. This results in a lower average breaking load.

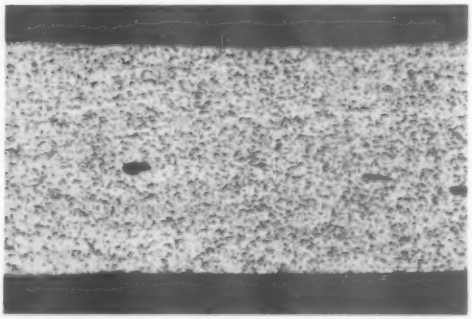

Fig. 5 Aluminum to aluminum weld showing effect of irregular surface

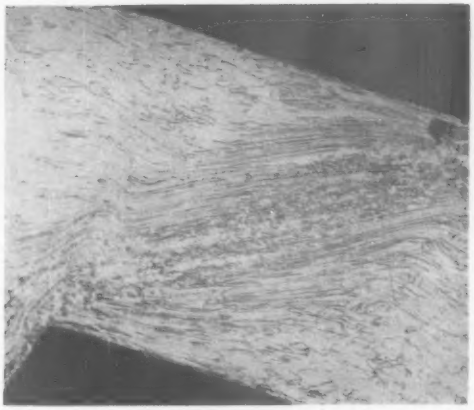

Fig. 6 Copper to copper weld

In each case, the size of the punches used is listed in the table. When a ductile metal like aluminum is welded to a less ductile one like nickel, it is desirable to use a narrower punch on the nickel in order to obtain about the same penetration in the nickel as in the aluminum.

The table demonstrates how the Figure of Merit decreases, and the welding pressure increases, as the metals become harder and less ductile.

STRUCTURE OF WELDS

Figure 4 is a photomicrograph of a cold-pressure weld between two strips of Type 2S aluminum. This material contains considerable impurities, which help to show the flow lines in the metal. There is, however, no indication of the exact location of the original interface between the two welded strips.

Figure 5 shows another weld between two pieces of aluminum, used in the home freezer unit. It reveals neither flow lines nor the original position of the inter-

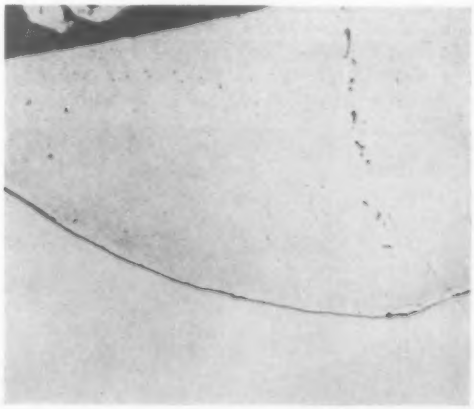

Fig. 7 Copper to aluminum weld

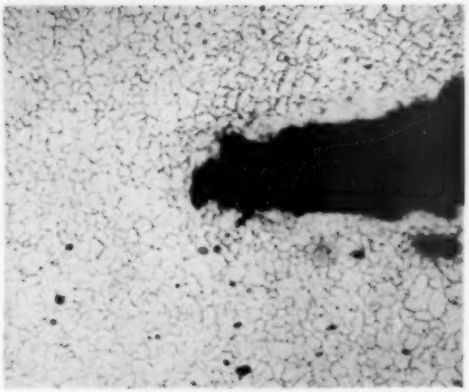

Fig. 8 Dow Metal to Dow Metal

face. Figure 6 reveals the structure and flow lines in two pieces of copper which were cold welded.

Figure 7 shows a weld copper and aluminum. Etching has produced a slight difference in level between the adjacent surfaces of the two metals so that, when the specimen is illuminated under the microscope, a shadow is cast and the interface is apparent. A slight difference in color can also be distinguished in the photomicrograph; this alone would reveal the exact position of the interface.

Magnesium alloy (Dow Metal) cannot be welded at room temperature. However, at 300 to 400° C., it welds nicely, recrystallization takes place, and, as shown in Fig. 8, no trace of the interface can be distinguished.

EQUIPMENT NECESSARY FOR COLD WELDING

The equipment required for cold welding is very simple, as shown in Fig. 2. The die set used to hold the punches may be mounted in a machine and operated in much the same manner as a punch press. In this case, the amount which the punch penetrates the metal might be controlled by a cam or by some other means. The cost of such equipment is far less than that of the equipment required for electric welding, and the maintenance and upkeep costs likewise are smaller. In the case of aluminum, cold welding causes no pickup on the punches. On the other hand, line welding or spot welding of aluminum, by electrical means, requires constant cleaning of the wheels and electrodes because they pick up metal during the welding operation.

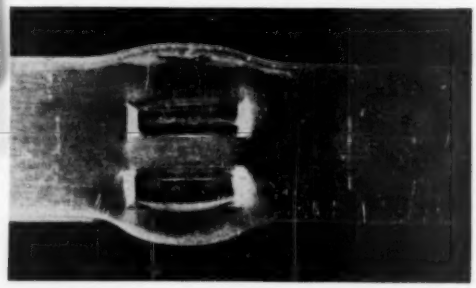

Fig. 9 Deformation in aluminum to aluminum weld

APPLICATIONS

While cold-pressure welding is not a "cure-all" method for joining metals, it has its field of application and it so happens that aluminum, one of the most difficult metals to weld by conventional methods, is quite easily welded by this method. Figure 9 shows two cold welds between two strips of aluminum, and the deformation which results from the operation.

Fig. 10 Miniature home freezer unit

Figure 10 is a photograph of a miniature home freezer unit cold welded by the British G-E Co. In the photograph, the unit is bottom side up to show the line weld along the flanged edges. This line weld was made with a wheel tapered to the shape of the punches, shown in Fig. 1, which was used to make the depression along the top flange, while a flat wheel was used as an anvil on the lower side. Small, rectangular welds are visible on the right front side of the box.

The depth of the depression made in the top sheet by the tapered wheel is greater than the thickness of the sheet; had the bottom sheet not flowed also, the top sheet would have been cut through. The top sheet is quite thin in the welded area, but is firmly joined to the thicker bottom sheet.

The British G-E Co. has produced cold-welded tubing by rolling up a strip of aluminum with flanges on the edges. These flanges, which are wire brushed before the tube is formed, are welded by passing them between two rolls which deform the metal sufficiently to produce a cold weld. The welded tube is passed through a machine which trims the welded flange and is then

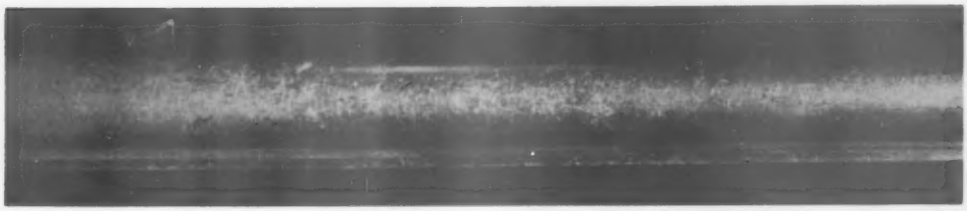

Fig. 11 Aluminum tubing

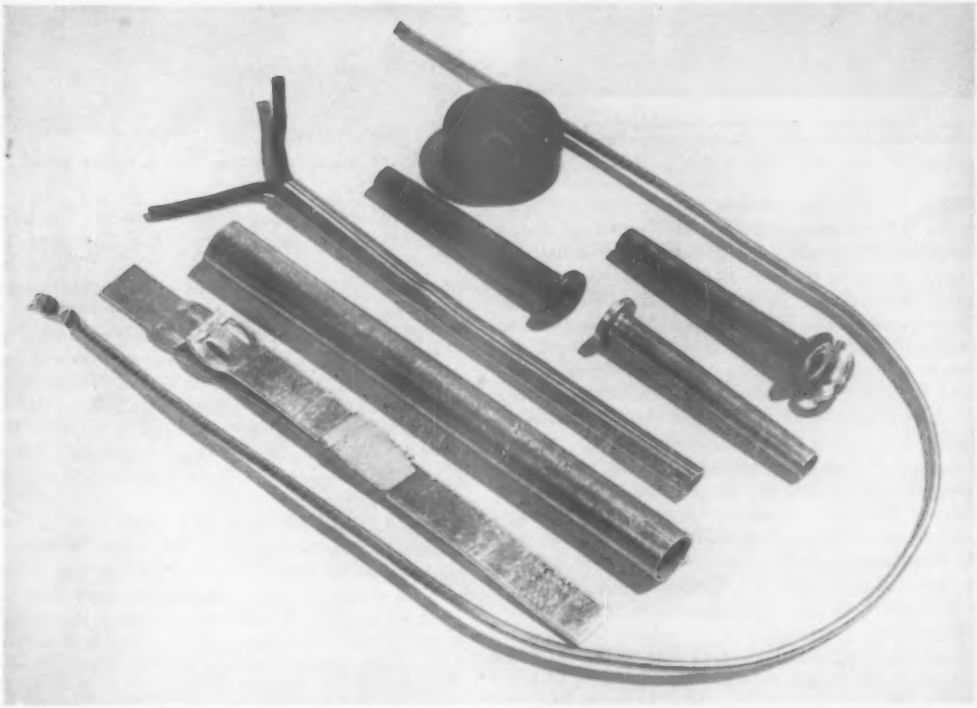

Fig. 12 Cold-welded specimens

ground to smooth up the trimmed edge. A piece of this cold-welded tubing is shown in Fig. 11. In the center of Fig. 12 is a flattened, cold-welded aluminum tube used for cable sheathing by the British. The wires can be seen protruding from one end.

The copper tubing used in the regulator of the G-E refrigerator has been sealed by pressure welding. Tests conducted on these welds have shown them to be vacuum-tight. The necked-down sections of these welds are about five to .005-.006 inches thick. Two such welds can be seen in the U-shaped tube shown in Fig. 12.

When aluminum is brazed or welded to copper, there is a tendency for a brittle alloy to form in the joint. Also, such joints are subject to electrolytic corrosion; they must be protected from the atmosphere by coatings which prevent moisture from reaching them. Figure 13 is a photomicrograph of a cold weld between copper and aluminum, which has been heated to 400° C. for 24 hr. Note the brittle copper-aluminum alloy formed by diffusion at the interface.

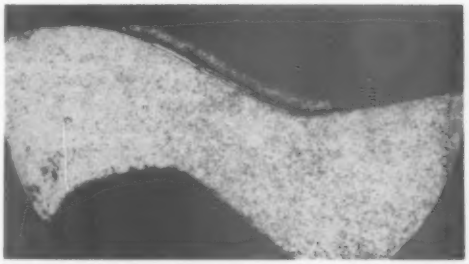

Fig. 13 Cold-welded joint between aluminum and copper after being heated at 400° C. for 24 hr.

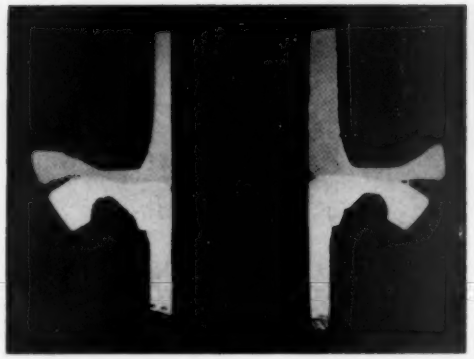

Fig. 14 Cross section of cold-pressure weld between copper and aluminum tubes. Magnification about 6 ×)

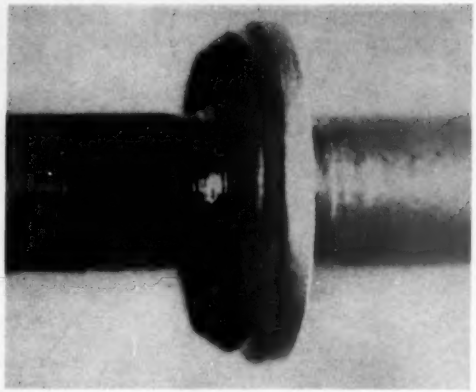

Fig. 15 Cold-welded aluminum to copper tubes

Since joints between aluminum and copper are used in the G-E refrigerator and it was desired to avoid formation of this brittle alloy, it was decided that an attempt would be made to cold weld flanged tubes of these two materials. Because the cold-welding operation requires drastic deformation of the metals, it was necessary to obtain special tubes, the ends of which were upset to produce a flange with a thickness about three times that of the tube wall. Two such tubes are shown in Fig. 12, next to the cable sheath mentioned previously. In this figure, adjacent to the two tubes, is shown a cold-welded specimen which was broken by inserting a chisel between the aluminum and copper flanges. The aluminum has been torn off at the periphery of the necked-down section of the weld, leaving an aluminum ring firmly welded to the copper flange. In this particular case the aluminum tube has been broken off at the inner portion of the necked-down flange.

Figure 14 is a photograph of a cold-welded section of aluminum and copper tubing. The thickness of the welded area is clearly shown. In order to make this weld, it was necessary to make the two ring-shaped dies with the proper contour to make the desired impression in the flanged materials. A close-fitting steel mandrel was inserted in the tubes to hold them in alignment and prevent the metal from flowing inward and partially closing the tubing when pressure was applied. It was also found necessary to hold the dies in perfect alignment to obtain satisfactory welds.

Despite the success of this process in joining the dissimilar metal tubes and eliminating brittleness, certain factors prevented it from being used in production. First, it was difficult to obtain, at a reasonable cost, tubes with flanges of sufficient thickness. Second, there is some question as to whether the strength of this cold-welded joint was great enough to meet engineering requirements. Figure 15 shows the flanged copper and aluminum tubes after cold welding.

The two pieces of aluminum strip shown taped together in Fig. 12 are pieces of a cold-welded specimen which was sheared by pulling in tension. The holes left in the upper strip, where it has sheared at the periphery of the cold weld, are evident. The metal torn from the upper strip can be seen standing in relief on the lower one.

It is obvious that when cold welding is considered for a particular application, the thickness of the material left in the necked-down section of the weld must be adequate to meet requirements. This is illustrated in the joining of wires which must carry current: the welded or necked-down section must have a cross section large enough to carry the required current without overheating.

As yet, there has been little application of cold welding in the production field. However, the strength of the welds, as indicated in Table 1, and their structure, as shown in Figs. 4 through 8, along with the applications cited, indicate that the use of this process might be extended greatly by applying it in certain fields and to metals other than aluminum and copper.

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Design Data for Brazing—Part IV

The material presented is design data recommended by the Welding Section of the Schenectady Works Laboratory and is being used by Design Engineers within the General Electric Co.

by W. J. VanNatten

IV. BRAZING PROCESSES (HEATING METHODS)

AFTER the parts to be brazed are designed, and the proper filler metal and flux specified, there enters the problem of determining the best method of heating to achieve the desired results.

It is generally agreed that consistent quality should result in a number of parts being brazed by any one specified process. The base metal and design of the joint together with the shape and size of the part or assembly, plays a great part in determining the brazing which process should be used for any particular application.

The brief descriptions of brazing processes given below should be used only as a guide in determining the process best suited for a particular job.

A. Resistance Brazing

Resistance brazing is a brazing process in which coalescence* is produced by the heat obtained through the resistance of the work to the flow of electric current in a circuit of which the work is a part, or by the resistance to current flow of the electrodes holding the work, using a nonferrous filler metal having a melting point above 800° F. but below that of the base metals. The filler metal is distributed in the joint by capillary attraction.†

Advantages

1. Rapid localized heating is possible.
2. Work may be set up for a fairly high rate of production.
3. This method of brazing is ideally suited for use with low-melting silver alloy filler metals. It is especially applicable for use with self-fluxing filler metals on nonferrous base metals such as copper, phosphor bronze, etc.

Limitations

1. Accurate temperature control is sometimes difficult.
2. Localized heating may cause some distortion of the work.
3. The size of an assembly which can be brazed by this method is limited.
4. This method of brazing is not practical at present for use with filler metals other than low-melting silver alloys.

Proper design for resistance brazed joints must necessarily allow adequate room for the electrodes on each side of the joint. The surfaces on which the electrodes bear should be flat and parallel, and preferably of uniform thickness. Figure 17 illustrates the setups for a few typical brazed joints.

Resistance welding machines are used for brazing in the same manner as for spot welding. The welding presses offer accurate timing and high-speed brazing

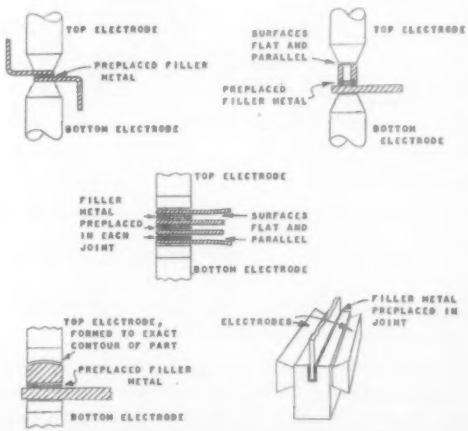

Fig. 17 Some preparations for resistance brazing

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* Coalescence expresses the idea of uniting or joining by growing together.

† Capillary attraction is the phenomenon by which adhesion between the molten filler metal and the base metals, together with the surface tension of the molten filler metal, distributes the filler metal between the properly fitted surfaces of the joint to be brazed.

on small assemblies. In cases where the brazing equipment must be brought to the work, portable brazing transformers with carbon block tongs are used. With any such equipment, heating is produced under pressure which is maintained until the filler metal solidifies. Clean, neat joints are obtained.

When resistance welding presses are used for brazing, the use of an electronic timing device will cut to a minimum the factor of human error. In the case of brazing with portable tong equipment, the skill of the operator plays a large part in determining the quality of the work.

B. Induction Brazing

Induction brazing is a brazing process in which coalescence is produced by the heat obtained through the resistance of the work to the flow of induced electric current, using a nonferrous filler metal having a melting point above 800° F. but below that of the base metals. The filler metal is distributed in the joint by capillary attraction.

Advantages

1. Good control of heat, with automatic timing, is possible. The human element is cut to a minimum.
2. Increased output is available through extremely fast heating.
3. Heating of the base material can be localized, preventing overheating of parts of the assembly other than those adjacent to the joint.
4. Versatility of induction heating permits low production, using single heating coils, or high production, using multiple sets of coils. This contributes to higher work efficiency.
5. In some cases it is possible to braze a number of joints on one assembly, yet keeping the heat localized in the vicinity of the joints. See Fig. 18.

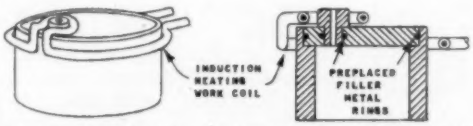


Fig. 18 Multiple induction brazing of a single assembly

Limitations

1. Localized heating may cause some distortion of the work.
2. Brazing with high-melting filler metals is not practical at present for high production work.
3. The size of an assembly which can be brazed by this method is limited.

Proper design of the parts for efficient induction heating is essential before the above listed advantages can be fully realized. In general, round or tubular sections are easier to heat by induction than are parts

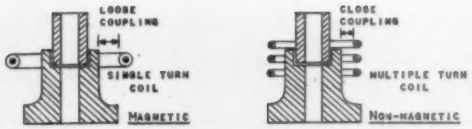


Fig. 19 "Coupling" of magnetic and nonmagnetic parts for induction brazing

of irregular shape. It is good practice to design parts in such a manner that the filler metal can be preplaced in the joint. The wall thicknesses at the joint should be as nearly alike as possible, in order to prevent unequal heating of the parts.

In heating magnetic materials, heat-producing losses are divided into two classes: hysteresis and eddy current losses. In nonmagnetic materials, only eddy current losses are present. It is usually found that magnetic materials may be "coupled" loosely, while nonmagnetic materials are "close-coupled." This is illustrated in Fig. 19. Figures 20 and 21 illustrate several typical joints which have been successfully brazed by the induction heating method.

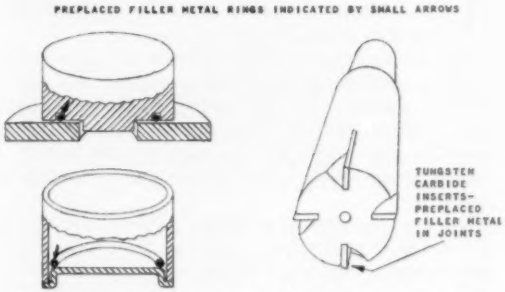


Fig. 20 Illustrations of typical induction brazed joints

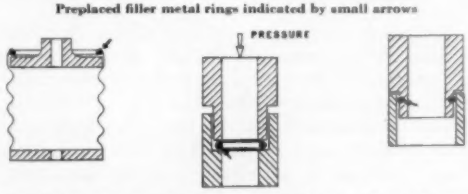


Fig. 21 (A) Illustrations of typical induction brazed joints

C. Furnace Brazing

Furnace brazing is a brazing process in which coalescence is produced by the heat obtained from a furnace, using a nonferrous filler metal having a melting point above 800° F. but below that of the base metals. The filler metal is distributed in the joint by capillary attraction.

Advantages

1. Uniform heating of parts, with minimum distortion.

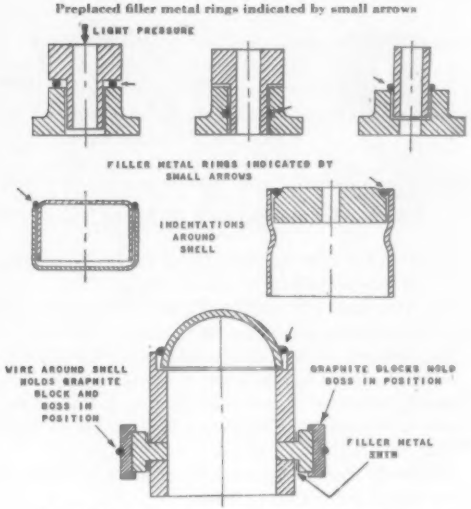

Preplaced filler metal rings indicated by small arrows
LIGHT PRESSURE
FILLER METAL RINGS INDICATED BY SMALL ARROWS
INDENTATIONS AROUND SHELL
WIRE AROUND SHELL HOLDS GRAPHITE BLOCK AND BOSS IN POSITION
GRAPHITE BLOCKS HOLD BOSS IN POSITION
FILLER METAL SWIM

Fig. 21 (B) Several typical furnace brazed joints

2. No residual stresses left in work.
3. Good temperature control is possible.
4. Good control of the surface condition (carburized, decarburized) of the parts is possible, depending upon the temperature and type of atmosphere used.
5. A wide range of filler metals is possible with the furnace brazing process.
6. Furnace brazing is ideal for mass production.

Limitations

1. Localized heating is not possible.
2. Parts joined by furnace brazing must be self-positioning, or jigs or fixtures must be used.

Proper design for furnace brazing must necessarily allow the filler metal to be preplaced in the joint. It is advantageous to design the parts so that they will be self-positioning during the brazing cycle, thus eliminating the use of jigs or fixtures. Figure 21 illustrates a few typical joints.

There are many types of furnaces which may be suitable for brazing. In general, a furnace is designed with two chambers—one in which the work is heated to the brazing temperature, and a second chamber in which the work is cooled.

Atmospheres are used which will insure good quality brazed joints as well as giving the desired surface conditions. By using the proper atmosphere, such surfaces as bright, oxidized, carburized, decarburized and others may be obtained.

D. Torch Brazing

Torch brazing is a brazing process in which coalescence is produced by heating with a gas flame, using a nonferrous filler metal having a melting point above 800° F., but below that of the base metal. The filler metal is distributed in the joint by capillary attraction.

Advantages

1. Cost of equipment is considerably lower than for other brazing processes.
2. Heating can be easily localized.
3. Torch setups can be made which will allow use of turntable and conveyor production systems.

Limitations

1. This brazing process usually requires skilled operators.
2. Torch brazing can be used only with low- or medium-temperature brazing filler metal.
3. Localized heating may cause distortion.
4. The work will oxidize quite rapidly.

Because of its low equipment cost, and flexibility, torch brazing is probably the most widely used brazing process. Torches can be used with a mixture of oxygen and a suitable combustible gas such as city gas, hydrogen, acetylene or liquefied petroleum gas, depending upon the source available and the particular application.

In many cases, torches are set up on conveyor lines, turntables, etc., for high-production work, producing high-quality brazed joints. For manual torch brazing, the quality of the joint normally depends upon the skill of the operator.

Torch brazing is most useful on jobs in which the design of the parts is such that numerous jigs or fixtures are required, the parts are irregular, or the base metals are unlike and/or of unequal cross-section area. Figure 22 illustrates a few typical joints which have been torch brazed.

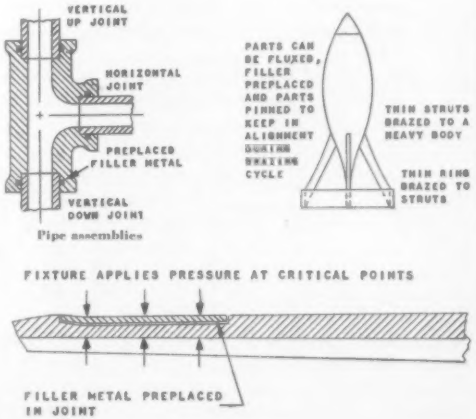
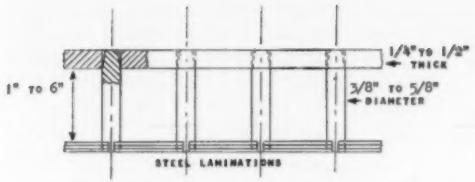

VERTICAL UP JOINT
HORIZONTAL JOINT
PREPLACED FILLER METAL
VERTICAL DOWN JOINT
Pipe assemblies
PARTS CAN BE FLUXED, FILLER PREPLACED AND PARTS PINNED TO KEEP IN ALIGNMENT DURING BRAZING CYCLE
THIN STRUTS BRAZED TO A HEAVY BODY
THIN RING BRAZED TO STRUTS
FIXTURE APPLIES PRESSURE AT CRITICAL POINTS
FILLER METAL PREPLACED IN JOINT

Fig. 22 (A) Typical torch brazed joints—parts of irregular shapes, unequal thicknesses and unlike base materials



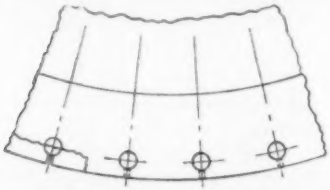


Fig. 22 (B) Typical torch brazed joints—heavy nonferrous ring brazed to lighter nonferrous bars

E. Dip Brazing (Metal Bath)

Dip brazing is a brazing process in which coalescence is produced by heating in a molten chemical or metal bath, and by using a nonferrous filler metal having a melting point above 800° F. but below that of the base metals. The filler metal is distributed in the joint by capillary attraction. When a metal bath is used, the bath provides the filler metal.

Advantages

1. Rapid localized heating of the joint area is possible.
2. Accurate temperature control is provided.

Limitations

1. Parts must be so designed that the "drag out" of filler metal is held to a minimum.
2. Only certain filler metals can be used. Usually those used are ones which do not contain low-melting metals which may volatilize from the bath.
3. The length of time of parts in the metal bath is critical. Excessive alloying between the filler metal and the base metal may occur if the time in the bath is not controlled.
4. The danger of explosions exists if wet parts are submerged in the metal bath.
5. Fixtures are usually required.

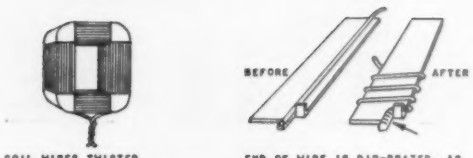

COIL WIRES TWISTED TOGETHER AND DIP-BRAZED IN A METAL BATH.
BEFORE
AFTER
END OF WIRE IS DIP-BRAZED, AS INDICATED BY ARROW, BEFORE THE WIRE IS WRAPPED AROUND PLATE.

Fig. 23 Typical metal-bath dip-brazed joints

Metal bath dip brazing is less widely used than torch, furnace, induction or resistance brazing, primarily because of the necessity of special joint design to limit "drag out" of the filler metal.

Figure 23 illustrates a few typical joints which have been dip brazed in a metal bath.

F. Dip Brazing (Chemical Bath)

Dip brazing is a brazing process in which coalescence is produced by heating in a molten chemical or metal bath, and by using a nonferrous filler metal having a melting point above 800° F., but below that of the base metals. The filler metal is distributed in the joint by capillary attraction.

Advantages

1. Heating of the parts is rapid, and can be localized to an extent depending upon the application.
2. Accurate temperature control is possible.
3. Flux is not required for most applications; the chemical bath can be neutral or reducing to act as a flux.
4. Most of the available filler metals may be used in this process. Both high- and low-temperature alloys are included.
5. Single or multiple joints may be brazed on one assembly, and will depend upon the design.

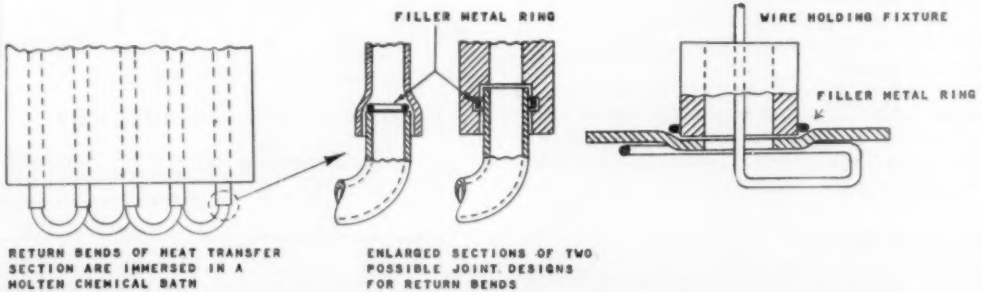

FILLER METAL RING
WIRE HOLDING FIXTURE
FILLER METAL RING
RETURN BENDS OF HEAT TRANSFER SECTION ARE IMMERSED IN A HOLTEN CHEMICAL BATH
ENLARGED SECTIONS OF TWO POSSIBLE JOINT DESIGNS FOR RETURN BENDS

Fig. 24 Typical chemical bath dip-brazed joints

Limitations

1. After brazing, the parts usually must be washed in order to remove the salts.
2. Excessive oxidation may occur upon cooling.
3. The danger of an explosion may exist if wet work is submerged in the bath.
4. Jigs or fixtures are usually required.
5. The chemical bath may etch or pit the base metal unless proper control of time and temperature is maintained.
6. Parts must sometimes be preheated before immersion in the chemical bath, in order to increase the speed of production.

Chemical bath dip brazing is less widely used than other brazing processes. It has been used successfully in the brazing of aluminum parts, using aluminum brazing flux as the chemical bath. It has been used to braze steel parts with copper filler metal, etc.

Figure 24 illustrates a few joints which have been successfully made by dip brazing in a chemical bath.

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Hardfacing Alfalfa Pulverizing Hammers

ALFALFA, used as an ingredient in livestock feed, is processed before use by the rancher or farmer. Recently, the service life of the pulverizing hammers which prepare the grain for dehydration has been greatly increased by the application of hardfacing. One hundred and twenty of these unfaced hammers, mounted on a revolving cylinder, averaged 50,000 tons of alfalfa. Hammers hardfaced with Airco Tungtube 40 by a mid-western farmer's co-op pulverized 350,000 tons before requiring refacing.

Figure 1

Figure 2

Figure 1 shows the longitudinal edge of one of these hammers being hardfaced with Airco Tungtube 40. For production work, twelve hammers are clamped together so that the flame will preheat the hammer adjacent to the one being hardfaced. Each hammer is hardfaced on four corners.

Figure 2, upper left, shows a worn hammer, ground on one end for hardfacing and already hardfaced on the opposite end. In the center is a hammer hardfaced on the bottom longitudinal edge with the top and side edges not yet hardfaced. Hardfacing has been completed on the bottom hammer, and since dressing is unnecessary, is ready for operation. Hammers are hardfaced $1^1/_2$ in. from the corners on the longitudinal edges and $^1/_2$ in. from the corners on the short edges. Only $1^1/_4$ in. of $^5/_{32}$ in. of hard facing rod was required to hardface one hammer.

Auto Body Repair

by R. E. Scott

DESIGN of the present-day automobile with its large body panels and fenders makes replacement of damaged areas an expensive job. However, repairs can be made quickly and economically with the help of oxyacetylene cutting and welding. A good example of this is illustrated in these body-repair pictures.

The right rear panel of this two-door sedan has been pushed in and the body metal torn. The repair could have been made by replacing the entire panel which includes all of the area from the door post back to the trunk compartment. However, this would have been an expensive repair, and since only the forward half of

R. E. Scott is with The Linde Air Products Co., a division of Union Carbide and Carbon Corp., Kansas City, Mo.

Fig. 1 The damaged right side panel is shown here. The chromium rub rail and interior upholstery are removed before repairs are started. The wheel was removed to prevent damage

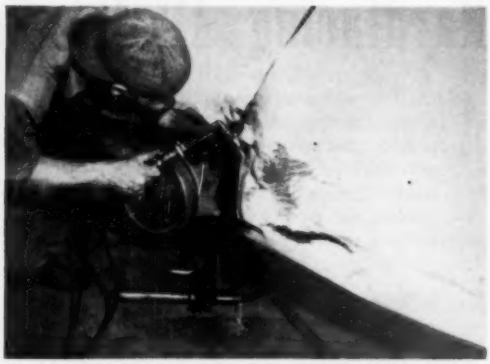


Fig. 2 After marking the area to be cut, the operator uses a cutting attachment with small nozzle to make a diagonal cut. Be sure there is no flammable material near-by

Fig. 3 Now the panel is cut along the upper edge to the door frame. A jog is made when the cut reaches the frame and the cut then passes through the frame to complete the cutting

Fig. 4 After the damaged section is removed, the car looks like this. The rip in the lower forward edge of the fender has gone through to the underbody, as seen here

the panel has suffered damage, would not be the most practical method.

By using a cutting attachment and a welding blowpipe, repairs were easily made. First, the damaged portion of the panel was cut out and then replaced with a similar section from a spare panel assembly. After the new section was welded in place, the seams were leaded and polished smooth. Then the panel was painted. The remaining parts of the spare panel were saved and used for other repair jobs.

Figures 1–10 show how one body shop does this type of repair.

Fig. 5 A cut was made in the underbody for straightening purposes. After welding, the weld seam and surrounding area are smoothed by filing before the new panel is fitted

Fig. 6 Here the operator is cutting a replacement section from a new panel. It is important that this section be cut to the exact size of the portion it replaces

Fig. 7 The new section is mounted in place and held by tack welds. Steel rod is used for the job and enough welds are made to assure exact alignment

Fig. 8 Now the operator goes back over the tack welds with steel rod to make a smooth continuous weld. A small flame and a good steel welding rod are used

Fig. 9 When the weld is completed, the excess metal is ground down. Lead is then deposited over and around the seam to provide a smooth finish to the area

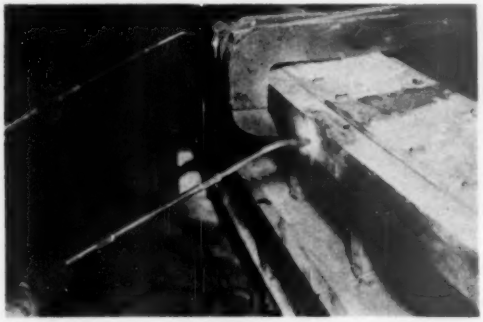
Fig. 10 After a factory-type repaint job, the car is as good as new. That means another satisfied customer for the shop—the best kind of advertising you can get

Cost Cut by Flame-Straightening

FLAME-STRAIGHTENING is saving a West Coast fabricator approximately $2000 a year since the method was adopted to straighten about a hundred heat-warped steel boxes each year. The boxes were formerly straightened cold, using a 50-ton jack. Considerable cutting and rewelding were required, and 60 to 100 man-hours were needed for each box. Now the job is done in about 30 hr. with flame-straightening.

Two operators, using oxyacetylene heating blowpipes, heat a triangular patch in the sides of the boxes while force is applied with the 50-ton jack. By this method the sides, 16 ft. long, 4 ft. high and topped with 12-in. extra heavy channel, are pulled back into shape. The flame-straightening method also eliminates an undesirable twist caused by exposure to heat. Cold straightening failed to remove this twist.

Fig. 1 Two operators heat triangular patches in the side of a steel box, 16 ft. long, 10 ft. wide and 4 ft. high, that has been warped by long exposure to heat. A 50-ton jack, between the two torches, is pulling the side in as heat is applied



Photos courtesy Linde Air Products Co.

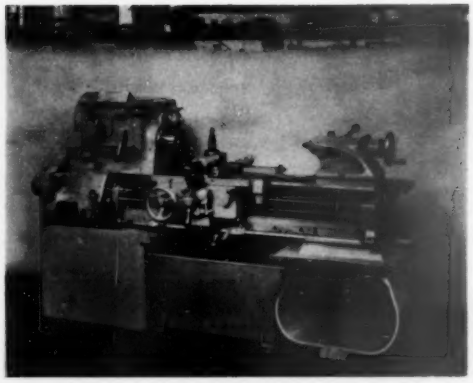
Fig. 2 In this close-up of the flame-straightening operation, the two oxyacetylene heating blowpipes are being used to heat the bases of the triangular patches between one hook of the 50-ton jack

Welded Steel Components Make Lathes Shock Resistant

MOST naval vessels carry some machine tools for making emergency repairs. In World War II certain cast-iron components of machine tools on vessels bombed or rocked by near misses were shattered, not only putting tools out of commission, but creating dangerous hazards to personnel.

This experience has led to demands for machine tools that are more shock resistant. Springfield Machine Tool Co., Springfield, Ohio, cooperating with design consultants of The Lincoln Electric Co., has answered this demand by producing lathes whose beds and legs are weldments fabricated from steel. Such lathes are not only much more shock resistant but the steel is both stiffer and stronger and the chance of shattering is nearly eliminated.

In addition novel forms of leg structure are used and are designed not only to resist shock and the stress of deck weaving but are so made that shocks are cushioned and largely absorbed before they can reach the bed. Moreover, the bed (upon which the accuracy of lathe



New Springfield lathe with bed and legs fabricated from steel by arc welding. Shock resistance is greatly increased for the welded components over the cast-iron counterparts displaced

work largely depends) is so mounted that leg distortion cannot twist the bed.

Naval authorities have been favorably impressed by the new design and method of fabrication and, after inspecting a scale model, placed orders for full size 14- and 16-in. lathes recently completed. One such is here illustrated and is expected to have far-reaching effects upon future machine tool purchases for naval use.

Experience gained may even affect machine tool design for conventional applications, especially as welded structures are displacing castings in many types of machines and other equipment and new welding procedures are much faster and result in lower welding costs. In welded structures substantial weight savings result (as they did to the tune of about 7% in the lathe here considered) and such savings are of increasing importance where metals are in short supply.

Rotary Fixture Welds Plowshares, One a Minute

USE of an eight-place rotary fixture has increased the production of welded plowshares by 10%. The rotary fixture in the Allis-Chalmers plant at LaCrosse, Wis., holds the parts of the plowshare in position and moves them under a Unionmelt welding head at the proper speed.

The plow consists of a die-cut gunnel and a forged share, which are welded together. One operator inserts these parts into the fixture and locks them in place with air clamps. The edge of the share meets the gunnel at an angle of 22° and thus provides a welding vee. A copper bar backs up the joint, so that a fully penetrated edge weld can be made.

As the table moves the assemblies beneath the welding head, granulated Unionmelt composition covers the welding zone. The weld is started at the precise moment when the edge of the assembly passes beneath the welding rod by a momentary discharge of high-frequency power which provides a path to initiate the flow of welding current. With the welding action established, the voltage control takes over and automatically governs further operation. A portion of the granulated composition fuses in the welding zone, excludes the air from the weld, and conducts the current from rod to workpiece. Welding takes place without flash, glare or spatter. For this application, the welding current is about 500 amps. at 35 v. alternating current. The clean, dense welds are made at the rate of 19.1 in. per minute.

As the share moves past the welding head, a vacuum unit recovers the unfused welding composition and returns it to the hopper for re-use. A second operator then removes the welded shares from the fixture. If the fused welding composition were allowed to cool completely, it would snap off by itself. In this high-speed fixture, the fused composition cools sufficiently so that a little tap with a hammer causes it to drop off. This reveals the weld, which is so smooth and clean that no chipping or grinding is required.

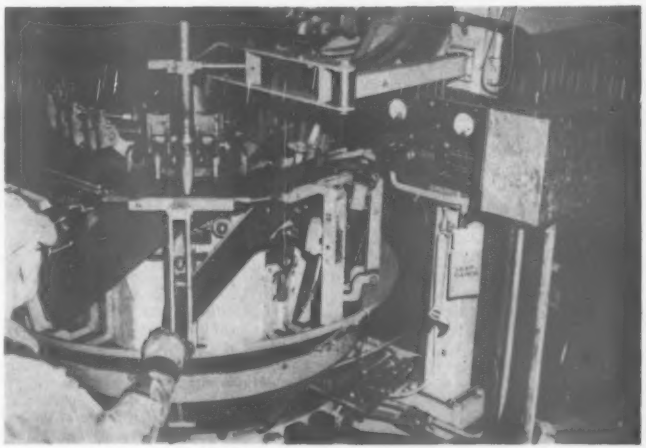


Fig. 1. Plowshares are welded automatically with Unionmelt equipment as they pass beneath the welding head of this rotary fixture

One fundamental problem in the design of this fixture was caused by the fact that the share moves in a circle beneath the welding head, while the joint to be welded is a straight line. The fixture had to be designed to move the welding head also, so that the combined motions result in a straight-line weld. The problem was solved neatly by using an eight-faced cam which causes the welding head to swing in and out; this combines with the circular motion of the table and produces the desired result.

With one man to load the fixture and another to unload it, production of the machine averages from 60 to 65 completely welded plowshares per hour. In addition to giving a 10% boost to production, the machine-welded plowshares are stronger, longer-wearing and better fitting than the ordinary forge-welded plowshares.

the AMERICAN WELDING SOCIETY

activities • related events

Detroit Hotel Facilities

As announced previously, the Annual Meeting of the AMERICAN WELDING SOCIETY is scheduled in Detroit, Mich., starting Sunday, Oct. 14, through Friday, Oct. 19, 1951.

The A.W.S. Annual Meeting, for many years, has been held in conjunction with the National Metal Exposition. Accordingly, the Annual Meeting is subject to convention in the same city, at the same time, as the National Metal Exposition. The National Metal Exposition Management selects the city for the activity each year.

In the past, these cities have been Atlantic City, Philadelphia, Cleveland, Detroit and Chicago. However, there has been no appearance of the National Metal Exposition in Detroit since 1938. The Management of the National Metal Exposition advises that there was a strong demand from industry for an appearance in Detroit and, accordingly, they made arrangements for such in 1951.

Unfortunately, Detroit is not in a position to provide the volume of hotel accommodation facilities comparable to, for example, Chicago. Our SOCIETY, like other participating Societies, is allocated but one hotel as its headquarters. Our hotel is the Book-Cadillac. But due to the tremendous demand for hotel accommodations in Detroit in ordinary times to accommodate the automotive industry, and now in this period of conversion from peacetime to defense activity, no Detroit hotel is in a position to set aside as many of its rooms for the purpose of a national convention as it would like. They must withhold the greater number of their rooms and other facilities for accommodating their local industries. This means that even in our headquarters' hotel, we are limited to a smaller number of meeting rooms, guest rooms and suites than other cities can provide. Our SOCIETY sent its membership room reservation blanks, with letter, on Apr. 13, 1951. The letter stressed that hotel reservations should be made promptly in that we had been allotted a limited number of facilities by the Hotel Book-Cadillac. The return mail applications to the Book-Cadillac on the first day included more requests for facilities than were available at that hotel. Within three days, there were three times as many requests as available accommodations.

Naturally, there have been numerous disappointments as many of our members and a number of the companies supporting our SOCIETY activities have perforce been advised that there are not sufficient accommodations available at the Hotel Book-Cadillac and that their applications have been referred to the Housing Committee, as was noted in Footnote 1 on the hotel reservation form. The Housing Committee will be composed of Detroit Representatives of each of the Societies and the Detroit Convention Bureau. While it is unfortunate that we cannot provide or assure accommodations for everyone in the headquarters' hotel, the Book-Cadillac, all applicants can be assured that every effort will be made to provide them accommodations in a hotel in Detroit not too distant from the headquarters' hotel. Those who have made applications and cannot be accommodated at the Hotel Book-Cadillac, but who can be assigned to other hotels, will be apprised during the month of August.

Much to the regret of our SOCIETY, the Detroit hotel facilities are limited but we assure all members that the SOCIETY is making every effort to provide accommodations for its members of a type and quantity meeting, as nearly as possible, their specific requirements. At this time, indications are that there will be a very heavy attendance at the Detroit Annual Meeting and National Metal Exposition.

The National Metal Exposition is to be located in the Michigan State Fair Grounds in the northern portion of the city, at Woodward and State Fair Avenues, approximately eight miles from the city center. There are a number of excellent motels in the area nearby which can be made available to our membership. Those members who are driving their cars to Detroit and will wish to use their cars while there, will find these motel accommodations superior to and more economical than city center hotels, particularly if they are obliged, by nature of their activity, to spend a large portion of their time at the Exposition area. These motels are within an approximate five mile distance from the Fair Grounds, provide adequate automobile parking facilities and offer the further advantage of quick travel to the Fair Grounds uninterrupted by the heavy Detroit city traffic. Some of these motels offer splended accommodations in the order of twin-bed rooms at $7.50 and $10; double-bed rooms ranging from $4.25, with connecting bath, to $6.50, $7 and $10 for a room with private bath. Rates are for single or double occupancy. Extra cots can be provided at $1.50 in some of the rooms. Excellent restaurants are located not over one quarter mile distant. Those members who wish to take advantage of these "close to the Exposition" accommodations should mail their applications to R. H. Bennewitz, Chairman, A.W.S. Housing Committee, c/o 6-240 General Motors Bldg., Detroit, Mich., as soon as possible. Application should state type of rooms required and the price range. Assignments will be made on the basis of date and time received and subject to the number of these accommodations available.

We look forward to serving our membership visiting Detroit in the best manner possible subject to the limitations of the available facilities.

THE SECRETARY

Board of Directors Meeting Minutes

The fourth meeting of the Board of Directors for the 1950-51 year of the AMERICAN WELDING SOCIETY was held on Thursday, May 10, 1951, at 10:00 A.M. in Room 34 of the Hotel Cleveland, Cleveland, Ohio, with the following in attendance:

Members: H. W. Pierce, *Chairman*, C. H. Jennings and F. L. Plummer, *Acting Chairman*, and L. C. Bibber, J. J. Chyle, T. J. Crawford, A. F. Davis, J. Grodrian, LaMotte Grover, J. H. Humberstone, T. B. Jefferson, A. J. Moses, H. E. Rockefeller, G. N. Sieger, H. N. Simms, L. C. Stiles, J. R. Stitt and C. B. Voldrich.

A.W.S. Staff: J. G. Magrath, *Secretary* and F. J. Mooney, *Assistant Secretary*.

Guest: C. D. Evans, Chairman, Technical Activities Committee.

Cleveland Section Representatives: J. B Austin, C. T. Elder, J. J. Jarms, R. J. Kriz, J. F. Maine, J. S. McKeighan, E. T. Scott, J. F. Wagner and J. C. Wyss.

Absentee Members: C. A. Adams, A. G. Bissell, W. F. Boyle, R. S. Donald, O. B. J. Fraser, H. O. Hill, Gilbert S. Schaller, H. S. Swan and A. E. Wisler.

Professional Membership

The Secretary reported that in his Section visits, wherever possible, he met with the Executive Committees of the Sections in a special meeting. He outlined to them the decision of the Board of Directors to create a new membership classification, to be known (tentative designation) as "Professional Membership." Of twenty-two Sections, the Section vote was 18½ favorable, 1½ neutral and 2 unfavorable. Of the two hundred Officers attending these sessions, their vote was 157 favorable, 25 neutral and 18 unfavorable. Accordingly, he has reported these results to the A.W.S. Special Committee on Membership Classification.

The greatest advancement in welding torch design and construction was made when NATIONAL engineers developed and patented the better way of making an effective, leakproof, damage proof joint between mixer and welding torch head; between cutting attachment and torch butt.

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Company Membership

The Secretary reported that of eleven Sections whose interest was engaged in the possibility of substituting a Sustaining "Company" Membership in place of the present Sustaining (Individual) Membership, the Section vote was 7 favorable, 3 neutral and 1 unfavorable. Of the one hundred and fourteen Officers in the foregoing 11 Sections, their vote was 75 favorable, 28 neutral and 11 unfavorable. The results of this activity have been reported to the A.W.S. Special Committee on Membership Classification. The institution of this change would require a change in the SOCIETY's Constitution, as well as the By-Laws.

Western Metal Congress

The Secretary reported that he attended the Western Metal Exposition and Congress held in Oakland, Calif., Mar. 19–23, 1951. The Exposition was held in the Oakland Exposition Hall. There were 15 exhibitors from the welding industry, which included 11 on welding and cutting, 3 on brazing and welding and 1 on metal spraying. There were 123 miscellaneous metals and heat-treating exhibitors and 9 publicity publications and promotion exhibitors. This totaled 147 exhibitors. The San Francisco A.W.S. Section arranged the technical meetings for our SOCIETY without help from National Headquarters. There were four papers on Monday, five on Tuesday, five on Wednesday, three papers and a business forum on Thursday and three papers on Friday. On Thursday, the A.W.S. Section gave a cocktail party prior to a dinner in which all the participating societies engaged. The monetary return to the San Francisco Section from the Western Metal Exposition for its participation in the Western Metal Congress was $750. This did not pay their total expenses.

At the meeting of the Executive Committee of the San Francisco Section, with the Chairman of the Los Angeles Section attending, both the San Francisco and the Los Angeles Section Chairmen went on record as stating that they felt that the national SOCIETY would have to help the local Sections in future Western Metal Congress activities. They no longer can devote the time required to this activity. Further, it was necessary that it have national support and more widespread publicity by the national SOCIETY in order to build up the attendance and warrant the expenditure of time and money.

Ohio State Welding Engineering Conference

The Secretary reported that he attended the Ohio State Welding Engineering Conference held in Columbus, Ohio, on Apr. 13th and 14th in the Welding Engineering Laboratories of the Ohio State University. This is an activity conducted mainly by the Ohio State University and the A.W.S. Columbus Section. Several other Ohio Sections assisted to a minor degree. Not all Ohio Sections, however cooperated. Five papers were provided on Friday and six on Saturday. The Conference was very well attended with a registration of slightly over 200. A luncheon was held on Friday and Saturday in the College Cafeteria and a dinner on Friday evening at the Fort Hayes Hotel. The dinner was oversubscribed and a number of customers had to be turned away in that the room would not hold more. This was an excellent program of papers, very well arranged and very well received.

This was the 12th Annual Ohio State Welding Engineering Conference. The Ohio State University feels that it has contributed to the welfare of the welding industry by holding these Conferences. However, the activity has reached a scale which, as advised by Prof R. S. Green, the Director of the activity, will require that the national SOCIETY assist in this activity hereafter if there are to be future Conferences. They feel that it is time that the national SOCIETY takes over this activity as one of its regional events.

Welder Qualification

The Secretary reported that nine Section Officer groups, namely, Richmond, Los Angeles, Long Beach, San Francisco, Seattle, Salt Lake City, Denver, Kansas City and Indianapolis, a representation of 89 Section Officers, voiced their opinion

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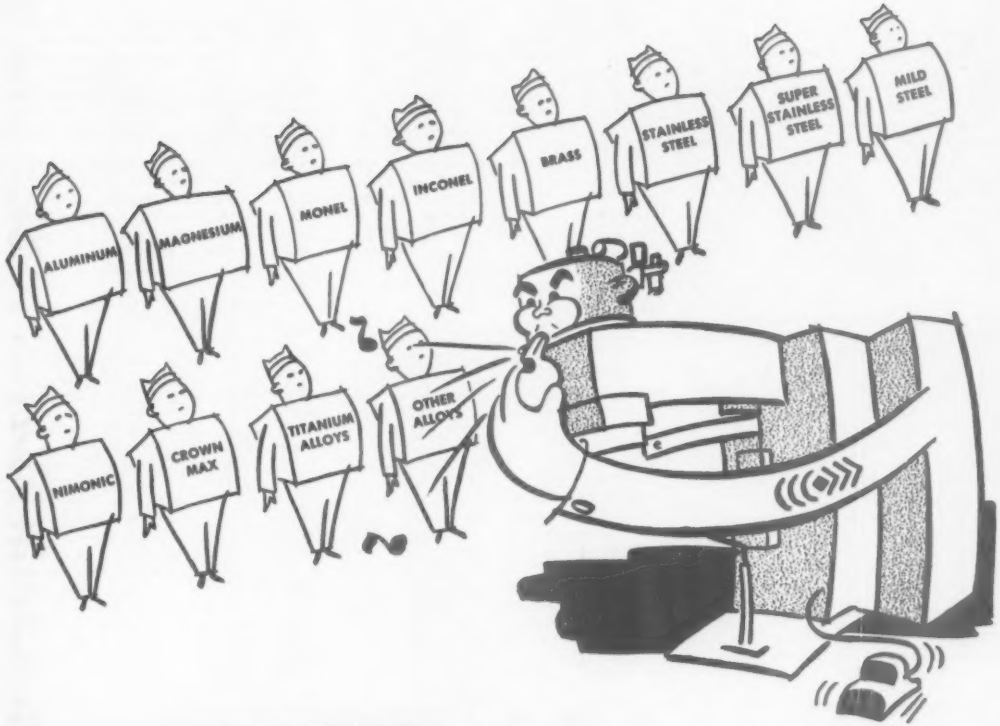

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that A.W.S. should either administer or sponsor a bureau or body which would institute a Welder "Certification" Program, administering such through an authorized nationally organized group of stations, such as, vocational schools, colleges, laboratories, certified proprietary organizations, etc., at least to the extent of benefiting industry and welders engaged in structural welding on public structures. He observed that the wording of the ruling of the Board of Directors, which is as follows: "Under no conditions shall the AMERICAN WELDING SOCIETY issue a certificate to a welding operator nor support a plan for the certification of welding operators, that denies a fabricator the privilege of qualifying his own welding operators," does not prohibit the SOCIETY from doing that which the Section Officers of Sections listed request. He pointed out the difficulties and unwarranted expense that structural fabricators face when they have to spend large sums of money for time, effort and materials for qualifying applicants for structural welding jobs, particularly on municipal works. Many of these welders have inadequate training and should have passed some sort of a preliminary certification test indicating their ability to weld, prior to the contractor having to spend his money on qualification, particularly when his competition—those fabricators who favor riveting, need spend no money on qualifying their labor. Not only is there the problem of simple and uniform welder qualification but there is also the problem of intelligent and adequate welder inspector qualification. It is the contention of those proposing the SOCIETY take some action, that unless such is done, there will be increasing resistance on the part of fabricators to consider bidding on structures for which welding is specified, or, where riveting or welding is optional, the contractor will take the course of least resistance and least expense and do the job by riveting rather than welding. This group asks for the following:

1. An authoritative uniform pattern for basic certification of welders (specific qualifications to be administered by contractor or industrial).
2. An authoritative uniform pattern for basic qualification of welding inspectors.
3. Simplified, readily understandable and comprehensive qualification procedure rules that can be incorporated in municipal and state laws.

It is further stated that "certification" does not mean final qualification. By "certification" is meant that the welder receives a certificate only on the basis of the simple guided bend test in the various essential positions on the basis of A.W.S. Qualification Procedure. Such would assure the contractor having only to stand the expense of further qualifying for his specific work those welders who have passed the fundamental "a, b, c's" of welding. The Secretary called attention to the fact that this or a similar proposal has been made to the Board of Directors of the AMERICAN SOCIETY a number of times during the past twenty years, in the order of the records of the minutes of Board meetings through that period. Similar recommendations have been tendered by many authoritative persons and bodies.

Attending members of the Board of Directors commented as follows:

J. J. Chyle stated that the Boiler Code has an agency for certifying welders known as the National Bureau for Certifying Welders. The establishment of similar agencies for other fields, such as pipe-line welding, etc., would be very desirable, the manufacturers to absorb the expense in qualifying welders.

H. E. Rockefeller observed that the Heating and Piping Association operates under the Piping Code by following A.S.A. The contractors support the qualifying of the individuals concerned.

R. J. Kriz, A.W.S. Cleveland Representative, reported that, in his opinion, the City of Cleveland has done a remarkable job of qualifying welders. His company, the James H. Herron Co., operates a testing laboratory and is certified by the American Council of Commercial Laboratories. He stated that in Cleveland, in the past, the practice was that the contractor paid the charges for qualification of welders. In the instance of his own company's laboratory, when the welders applied for qualification, in 90% of the cases the charges were paid by the individual welders.

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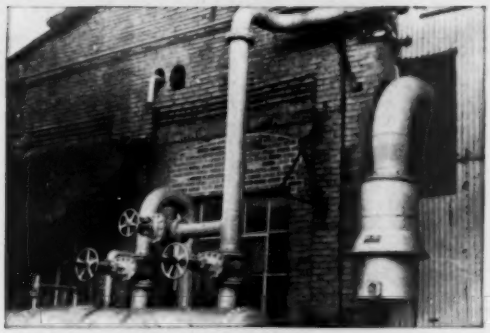
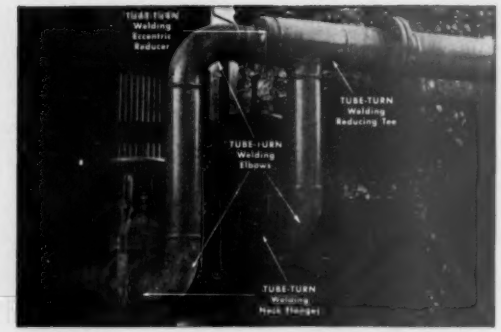
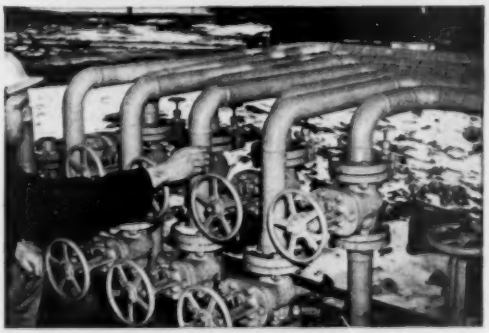


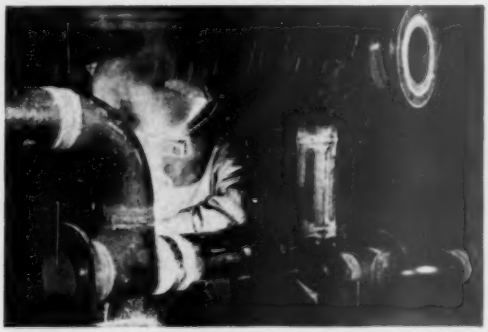
Welding complex process piping calls for a wide variety of fittings and flanges. In this installation, air is drawn into compressor through a 16-inch line, connected to an outdoor filter through a TUBE-TURN Welding Reducer. Air at 100 lbs. is piped to the compressor tank through an 8-inch welded line.



Manifold serves air lines to various shops. Matching the two 8-inch lines to the 12-inch line here was no problem. Use of a TUBE-TURN Reducing Outlet Tee and a TUBE-TURN Eccentric Reducer made the construction job easy. The main line can be opened easily at the TUBE-TURN Welding Flanges.



Small lines tap off fire foam chemical manifold, lead to storage areas and other critical locations. Leakage or weak joints here could be disastrous. Welded piping with strong TUBE-TURN Welding Fittings makes this fire protection reliable.



In fabricating, welders appreciate the true circularity of TUBE-TURN Welding Fittings. To fill an immediate need, a welding elbow is often cut to make an odd-angle welding fitting. Unique forging process assures that TUBE-TURN Welding Elbows can be cut at any angle and still match the pipe for proper welds.

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A. J. Moses stated that it is the function of A.W.S. to write the text of such tests to be given the welder for qualification purposes.

LaMotte Grover suggested A.W.S. approach the Association of General Contractors as there is a possibility that this organization might finance such a project.

The attending Board members felt that A.W.S. should explore all avenues and that it should definitely approach the American Council of Commercial Laboratories to determine if that organization could and would assist in the problem which is of paramount importance in the structural field. In view of the apparent urgency for action in the structural field referral should be made to the A.W.S. Building Code Committee.

Action: Upon motion, duly seconded, the Board of Directors voted that the problem and the development of a program be referred to the Building Code Committee for study and report back to the Board of Directors.

The meeting adjourned for luncheon at 12:30 P.M. and reconvened at 1:50 P.M.

A.W.S. Cleveland Section Chairman J. C. Wyss extended a cordial invitation to all Board members to be guests of the Cleveland Section at its 12th Annual Symposium and Dinner. Board members so responded.

Student Membership

The Constitution and By-Laws Committee met on Apr. 20, 1951, and recommended that the Board of Directors approve the following rewording for the Student Member by-laws, Article I—Membership; Section 2D—Student Members:

"A Student Member shall be an individual who is actually in attendance at a recognized college or university, taking a course leading to a degree. Student Members shall not have the right to vote or to hold office except in Student Chapters as may be provided for by the by-laws of the Student Chapter. At the termination of the fiscal year of status as a student, affiliation as a 'Student Member' *may be continued for one (1) additional year.*"

Action: The Board so approved.

Membership Billing

The Constitution and By-Laws Committee met on Apr. 20, 1951, and recommended the following revised wording in the SOCIETY's by-laws:

"*Article III—Resignation and Expulsion of Members*

"Section 3. Nonpayment of Dues. Any member whose dues to the SOCIETY shall remain unpaid for a period of six months *after they become due*, shall be duly notified by the Secretary by letter ballot to the latest post office address as it appears on the records of the SOCIETY, stating that if such dues are not paid within a period of one month, he shall automatically cease to be a member of the SOCIETY."

Memorial Resolution

Memorial Resolution for the late P. M. Mattern, as prepared by a Special Committee, consisting of J. H. Humberstone and W. Begerow, was submitted to the Board of Directors for approval thereon.

Action: Upon motion, duly seconded, Memorial Resolution, as submitted by the Special Committee, met with the unanimous approval of the Board of Directors. The Secretary was directed to send a letter to the New Jersey Section, in which Mr. Mattern had faithfully served as Secretary-Treasurer, advising the Section of this action and providing copy of text of Resolution.

Centennial of Engineering

Upon motion, duly seconded, the Board of Directors voted that (1) A.W.S. participate in the Centennial of Engineering to take place in Chicago, Ill., in 1952, and (2) President H. W. Pierce be empowered to appoint A.W.S. representatives to serve on Technical Program and General Arrangements Coordinating Committees of the Centennial of Engineering, 1952.

National Production Authority

The Secretary requested decision of the Board of Directors regarding Van Rensselaer P. Saxe's suggestion that A.W.S. approach the N.P.A. with its recommendation "that structural welding be used as a method of connection for structural steelwork at all possible places where riveting was normally used," and "that all structural steelwork would be designed for 24,000 psi. tension stress." He advised that this question had been referred to the A.W.S. Public Relations

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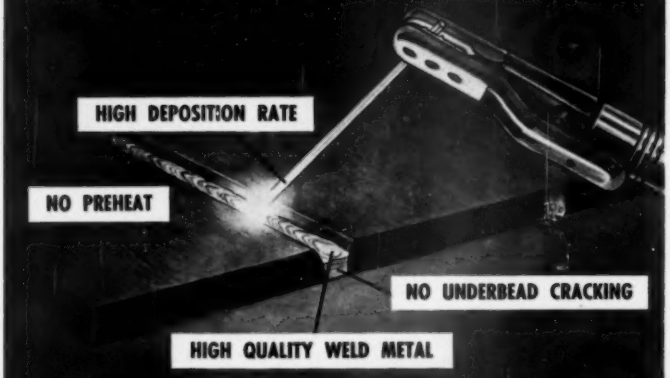

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Committee who advised its referral to Committee on Building Codes. Neither the Public Relations Committee nor the Chairman of the Committee on Building Codes appeared disposed to take direct action. The Chairman of the Public Relations Committee had suggested that the matter be decided by the Board of Directors should decision not be reached by other bodies. Discussion among Board members followed.

Action: The Board of Directors, upon motion, duly seconded, voted that A.W.S. directly approach N.P.A. and also urge fabricators and all others interested to do the same thing, basing their recommendations on previous experience of World War II. The Society's Secretary was delegated to so inform the N.P.A. on behalf of A.W.S., after consulting with the Society's technical authorities in regard to content of recommendation. The Secretary was also authorized to enlist the support of structural steel fabricators.

Membership Status Report

The Assistant Secretary reported that as of Apr. 30, 1951, our Society had a total membership registration of 7249, consisting of 7074 active members and 175 delinquent members. At the beginning of the membership year, Sept. 1, 1950, the Society had a total registration of 7132, comprising 6993 active members and 139 delinquent members.

In comparing membership registration as of Apr. 30, 1950, vs. Apr. 30, 1951, he reported that (1) active membership as of Apr. 30, 1950, of 6873 as compared to 7074 as of Apr. 30, 1951, resulted in a net increase of 201 members; (2) delinquent membership as of Apr. 30, 1950, of 283 as compared to 175 as of Apr. 30, 1951, resulted in a net decrease of 108; and (3) total registration as of Apr. 30, 1950, of 7156 as compared to 7249 on Apr. 30, 1951, resulted in a net increase of 93 members.

The Board of Directors, at a meeting held on Feb. 12, 1951, voted to extend the delinquency period on Aug. 31st "regular" renewals, one additional month, from Mar. 31, 1951, to Apr. 30, 1951. As a result of this action, 55 delinquent members remitted dues payment.

On Apr. 30, 1951, the Society removed 421 delinquent members from the rolls of the Society for reason of nonpayment of dues as compared to 617 delinquent members, for similar reasons, on Apr. 30, 1950.

Chairman National Membership Committee

Chairman Pierce reported that of twenty-one returns received on letter ballot submitted to the Board of Directors regarding the appointment of I. Morrison as Chairman of the National Membership Committee, for the 1951–52 year, all votes cast favored Mr. Morrison's appointment.

Membership Award

The Chairman advised that last year H. C. Neitzel, Chairman of the National Membership Committee, had donated two bronze plaques to be awarded each year to an A.W.S. Section which had attained, for that year, the greatest gains in membership (one plaque for percentage and one for total members). The President

suggested that he would entertain a motion calling for these awards to be given official status by the SOCIETY and to be hereafter known as the "Neitzel Membership Trophy" (or similar name) and that the recommendation be submitted for proper registration to the SOCIETY's Committee on Awards.

Action: The Board of Directors unanimously approved the President's recommendation.

Invitation from Columbus, Ohio

The Chairman advised that he and, to his knowledge, all other members of the Board, had received an invitation from the General Manager of the Columbus, Ohio, Chamber of Commerce to consider locating the SOCIETY's National Headquarters in that city. The Chairman stated that he was referring this invitation to the Special Committee on National Headquarters' Housing for consideration. The Secretary advised that additional invitations had been received from the President of the Columbus Chamber of Commerce, the Director of Battelle Memorial Institute, the President of Ohio State University, President of Columbus Convention Bureau, President of Columbus Technical Council, Vice-President of The Jaeger Machine Co., President of The Seagrave Corp. and the District Manager of Williams & Co., Inc. The Chairman advised that these too would be referred to the Special Committee on Headquarters' Housing.

Invitation to I.I.W.

A. F. Davis stated that in conversation with R. M. Gooderham, General Manager of the Canadian Welding Bureau, Mr. Gooderham stated that he will attend the meeting of I.I.W. in England in July 1951, and that following the meeting, he will invite members of I.I.W. to visit with him in Canada.

Cleveland Section Directory & Buyer's Guide

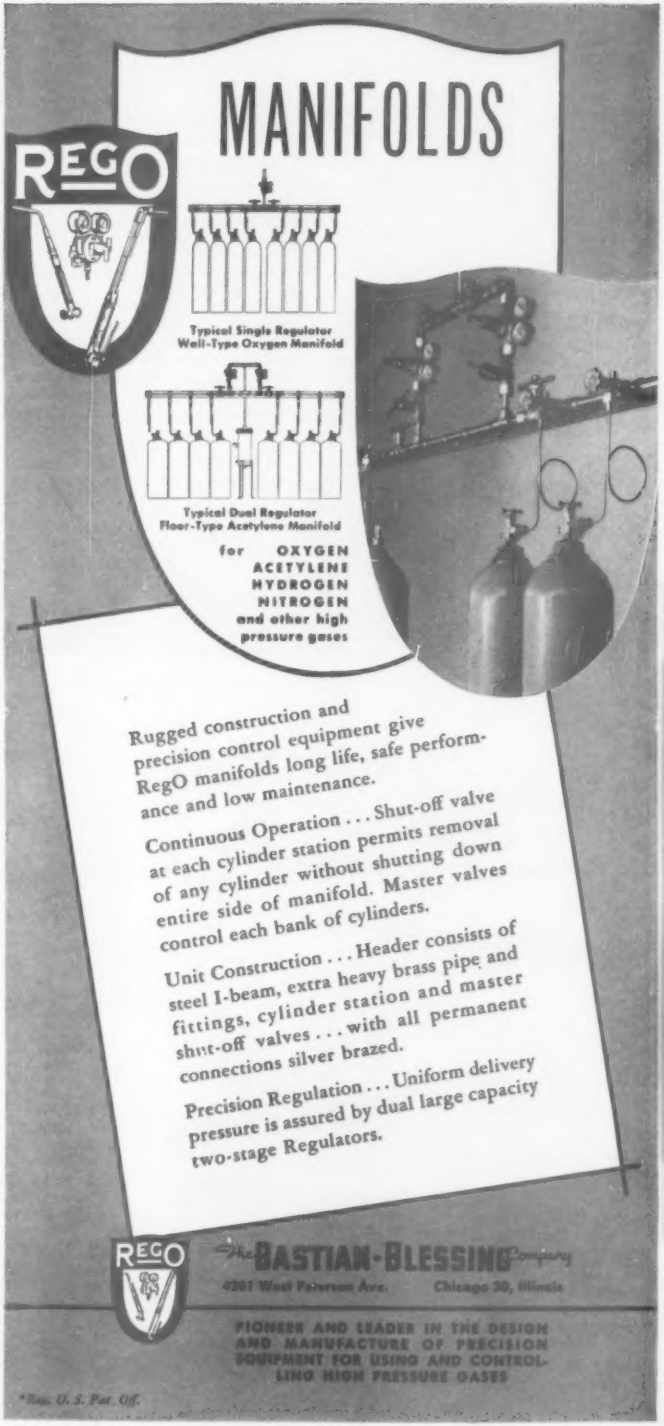
Members of the A.W.S. Cleveland Section were complimented by the attending Board members for their most excellently prepared Directory and Buyer's Guide issued in conjunction with the 12th Annual Welding Symposium.

Date of Next Meeting

The next meeting of the Board of Directors of the SOCIETY was scheduled to take place on Tuesday, Aug. 28, 1951, in New York City.

A. F. Davis Undergraduate Welding Awards

To stimulate undergraduate interest in welding, the AMERICAN WELDING SOCIETY offers annually the A. F. Davis Undergraduate Welding Award. The first prize consists of $200 to the author of the best paper on welding and $200 to the undergraduate publication in which the article appears. This year Edwin L. Marshall was the recipient of the first prize. The award was made at the class night exercises held on June 4th by Dean Thorndike Saville of New York Univer-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sity, College of Engineering. This award was made by the AMERICAN WELDING SOCIETY and in presenting the award Dean Saville remarked, "This is a fine tribute to his own abilities, and redounds greatly to the credit of the *Quadrangle* and of the College of Engineering."

A.W.S. Brazing Committee Meets

The A.W.S. Committee on Brazing and Soldering took time out from its work on June 8th, to inspect the new plant of the Eutectic Welding Alloys Corp.

The inspection trip enabled the members to secure information on brazing filler metals and their application, which will be useful in preparation of a Brazing and Soldering Manual on which the Committee is now working.

The accompanying photo was taken during a brief pause for lunch.

New Sustaining Member

It is the SOCIETY'S pleasure to welcome Chas. F. Guyon, Inc., as a new Sustaining Member in the SOCIETY, with Zir Geyari of its Harrison, N. J., office as their Sustaining Member representative. Listed are the products or services of Chas. F. Guyon, Inc.

The main office is located at 501 Fifth Ave., New York 17, N. Y. In its 28-acre plant, the former Atha Works of the Crucible Steel Co., in Harrison, N. J., the company is engaged in sales and distribution of pipe, fittings and valves of leading U. S. manufacturers. The company carries a full stock of butt-weld, lap-weld and seamless steel pipe, Byers wrought iron pipe, copper tubing, brass pipe and tubing, stainless steel pipe and a full line of valves, fittings and steam and oil specialties of leading makes in cast steel, cast iron, brass and stainless steel.

In its fabricating shops the company is engaged in cutting, threading, grooving, welding, bending and fabrication of pipe for all phases of industry—from radiant heating panels, shaped welding nipples, industrial process and power plant piping to pressure piping and unfired pressure vessels fabricated by welding under A.S.M.E. code requirements.

Plummer Named to National Research Council

The Board of Directors by letter ballot selected F. L. Plummer to represent the AMERICAN WELDING SOCIETY and Division of Engineering and Industrial Research of the National Research Council for a three-year term.

Mr. Plummer is currently second Vice-President of the SOCIETY and is active in the Pressure Vessel Research work of the Welding Research Council.

Members A. W. S. Brazing Committee Visit Eutectic Plant

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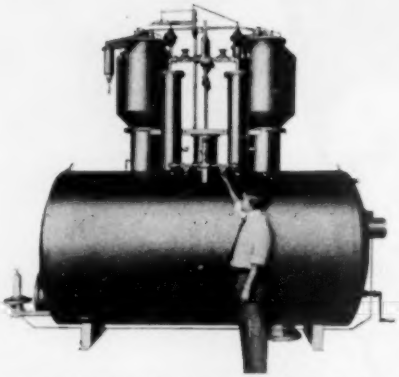

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WELDING CODES STANDARDS and SPECIFICATIONS

Are you fully informed on the latest welding standards available? Have you missed any of the earlier standards? This column is published as a regularly monthly feature of The Welding Journal to keep you abreast of AWS technical standards, which are universally recognized as the most authoritative source of welding information.

The list of publications shown below is only partial; it is changed from month to month.

Keep informed—Read this column regularly.

B. TRAINING INSPECTION AND CONTROL

Training, Qualification and Inspection

B1.1-45 Inspection Handbook for Manual Metal-Arc Welding (Emergency Standard) — **$2.00**

B2.1-45 Code of Minimum Requirements for Instruction of Welding Operators: Part A—Arc Welding of Steel — **75c**

B2.2-44T Code of Minimum Requirements for Instruction of Welding Operators: Part B-1—Oxy-Acetylene Welding of Steel Aircraft (Tentative) — **75c**

B3.0-41T Standard Qualification Procedure (Tentative) — **50c**

C. PROCESSES

Recommended Practices

C1.1-50 Recommended Practices for Resistance Welding — **$1.00**

C1.2-42T Tentative Standards and Recommended Practices and Procedures for Spot Welding Aluminum Alloys (Emergency Standard) — $1.00

C2.1-50T Recommended Practices for Metallizing: Part IA—Metallizing Shaft or Similar Objects; Part II—Metallizing—Safety Recommendations — **Together 75c**

NOTE: 25% discount to A and B members and 15% discount to C members of AWS on copies of any codes and standards listed above except starred items.

Send your orders, or requests for order forms containing complete list of AWS publications to:

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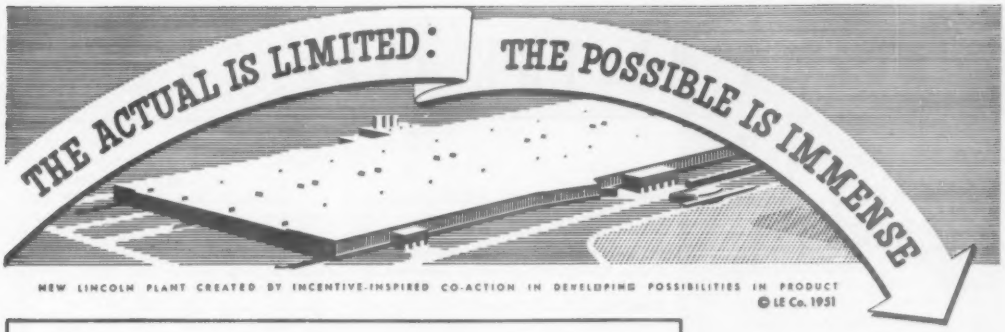

NEW LINCOLN PLANT CREATED BY INCENTIVE-INSPIRED CO-ACTION IN DEVELOPING POSSIBILITIES IN PRODUCT
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WHEN designs utilize the economies of welded steel construction, invariably costs are less. That's because fewer pounds of less costly material are needed . . . Each pound of metal can be more easily concentrated where it does the most good.

Wherever costs are higher, inevitably the designs have fallen short of embodying the potential savings, or the products themselves have been overdesigned. A careful reappraisal by the shop before a design is "frozen" simplifies construction details and eliminates every unnecessary expense for lowest cost of manufacture.

Your Lincoln Welding Engineer will gladly help you analyze your designs and point out various cost reduction possibilities. Simply call or write.

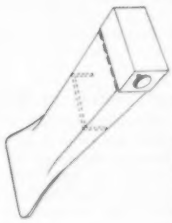

Fig. 3. Saves 51% Cost *by forming lever arm and pad as integral piece from 10 gauge metal. Weighs 2.5 pounds... costs 54¢.*

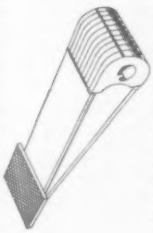

Fig. 4. Saves 67%. Eliminates Broaching. *Hub with integral key is produced by stacking stampings in assembly. Arm is 10 gauge, brake formed and welded to hub. Cost is only 31¢ . . . weight 2.2 pounds.*

the ACTUAL

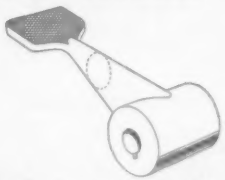

Fig. 1. Traditional Construction. *Machine foot-lever, 10 inches long, weighs 6 pounds. Cost with broached keyway is $1.15.*

increasing the YIELD

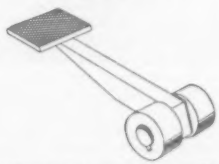

Fig. 2. Simple Steel Design Costs 34% Less. *Can be built by the shop with only saw and shears. Weighs 2.7 pounds . . . costs 68¢ complete with keyway.*

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NEWS OF THE INDUSTRY

Safety Congress

The 39th National Safety Congress and Exposition, to be held Oct. 8–12, Chicago, Ill. Sessions on industrial safety scheduled for Stevens, Palmer House, Congress and Morrison hotels; traffic safety sessions at Congress Hotel; commercial vehicle and farm safety sessions at La Salle Hotel; school safety sessions at Morrison Hotel, and home safety sessions at Stevens Hotel. For further information write R. L. Forney, general secretary, National Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.

Electrode Distributor

The Welding Equipment and Supply Co. of Detroit wishes to announce that, effective July 15, 1951, the Arcos Corp. of 1500 S. Western Ave., Chicago, Ill. will be the exclusive distributor of Eureka Tool and Die Welding Electrodes and Rods in the State of Illinois. They will also service the heavy industrialized area of East Chicago, Gary and Hammond, Ind.; the southern part of Wisconsin, including Milwaukee, and the Tri-City area of Moline, Rock Island and Davenport. Their operation will be headed by Walter List, capably assisted by John Collins, Bill Craske and Pat O'Shea.

The Arcos Corp. will maintain a complete warehouse stock of Eureka tool and die welding electrodes and rods.

The Arcos Corp.'s past experience in distributing Eureka electrodes on the East Coast will enable them to render an outstanding service on engineering problems pertaining to tool and die welding.

New A.S.T.M. President

The recently elected president of the American Society for Testing Materials is Truman S. Fuller, Engineer in Charge of Works Laboratory, General Electric Co., Schenectady 5, N. Y.

He was born in Saratoga Springs, N. Y., and graduated from Syracuse University in 1911 with a degree of B.S. in Chemistry. He entered the employ of the General Electric Co. as Chemist at the Edison Lamp Works, Harrison, N. J., on July 1, 1911. Three months later he was transferred to the Research Laboratory as Metallurgist at Schenectady. In 1938 he became Engineer of Materials, Works Laboratory; in 1943 Assistant Engineer of that division; and on July 1, 1945, was appointed Engineer in Charge of the Works Laboratory.

Participating in A.S.T.M. work for many years, Mr. Fuller is a former member of the Board of Directors, having served in 1939–41 and again in 1947–50. He was elected Vice-President last year and has been an active member of a large number of A.S.T.M. technical committees in many materials fields.

A writer of many papers, particularly on metals and alloys, Mr. Fuller also is active in the work of other technical organizations and holds membership in the following: American Society for Metals, American Institute of Mining and Metallurgical Engineers, the British Institute of Metals, and the British Iron and Steel Institute. He is a member of the Executive Committee of the Welding Research Council.

Research in Sweden

A special committee for the study of fatigue in metallic structures has been formed by the Swedish Engineer's Committee. Given the problem of attacking the fundamentals of fatigue the special committee has a four-point program: (*a*) to make an inventory of fatigue-testing equipment available in Sweden, (*b*) to collect information on fatigue research in progress and to examine new problems suggested by industry, (*c*) to study proposals for research with a view toward organizing, test programs, (*d*) to distribute the tests to be made among the available laboratories.

The Committee Chairman is Professor Weibull who published a statistical study of fatigue tests in the 1949 volume of *Acta Polytechnica*. The Committee expects to prepare a decimal classification of all articles on fatigue, and is seeking foreign collaboration, which seems assured with the U.S.A.

Fabricated Structural Shapes, Plates and Bars I.A.C.

The Fabricated Structural Shapes, Plates, and Bars Industry Advisory Committee at its second meeting, June 19th, conferred with OPS officials on the substance of a proposed ceiling price regulation for their products.

In general, industry representatives agreed with the suggested formula to regulate operating margins on the basis of dollars per ton obtained in the last quarter of 1950 on the contract most comparable to the one being priced.

Fabricated structural products are now under the machinery order, CPR 30, which specifies a pre-Korean base period, a time when the industry was relatively inactive. The industry manufactures countless products such as barges, buoys, cranes, industrial doors, tanks, fire escapes, girders, ladders, mixers, roof decks, radio towers, smokestacks, wind tunnels and others, as well as steel for bridges, railroads, buildings and so forth.

The committee asked for insertion in the regulation of a clause providing that a manufacturer selling a combined product and erection service who sustains a labor cost increase as a result of contracts entered into before March 15th to bring rates up to prevailing levels may apply for OPS permission to include a factor for this increase in his ceiling price.

Today's meeting was conducted by Howard Needham, Metals Branch consultant. Also present were William Kerber, branch chief, R. J. Benes, counsel, Hardy Burgess, consultant, W. H. Dupka, iron and steel section head, C. R. Wasson and W. R. Rogers, economists, and Harry Spack, Office for Advisory Committees.

The French Society of Welding Engineers*

At the Annual Meeting of the French Society of Welding Engineers in Paris, Jan. 25, 1951, the President, J. Nègre, announced a total membership of 767, compared with 702 the previous year. Of these 86 are sustaining members, and 78 are foreign. Receipts for the year totaled 1,205,800 francs of which 676,000 francs came from member's dues, and 442,000 francs came from sustaining members. Expenses for the year can be grouped under three headings: the Society's magazine, office and activities of the International Institute of Welding. Of the balance of 96,900 francs resulting from the year's operation, 20,000 francs were set aside for prizes. Dues were raised 10%. The society held technical meetings every month except July and August in 1950.

* Abstracted by Dr. G. E. Claussen, published in *Soudure et Techniques Connexes*, V, 27–30 (Jan./Feb. 1951).

Report of the Swiss Acetylene Society for 1950*

The first few months of 1950 were poor for business. Prices were lower and everyone wished to liquidate stocks. After the Korean war broke out, commercial activity increased greatly. By autumn scarcities became felt, particularly in steel plates, piping, structural sections, nickel, copper and some of its alloys, and light metals. Prices rose continuously and restrictions were necessary. By the end of the year copper and its alloys could be obtained at official prices only with great difficulty. The conjectural attitude of the world to the Korean conflict was reflected in our country too. Materials for the armament industries were in great demand. Because of this rising movement in Swiss business, exports of machinery reached a new high. In the same way welding and allied processes tended to slow down during the

* Abstracted by Dr. G. E. Claussen, published in *Journal de la Soudure*, 87–97 (May 1951).

first half of the year but quickly reached high levels of activity during the latter part of the year. However, the production and sale of calcium carbide did not exceed the preceding year. Despite all efforts it was found impossible to export carbide principally because possible importing countries were in unsatisfactory currency conditions. The sale of oxygen and dissolved acetylene was nearly the same in 1950 as in 1949. The price of oxygen is the same while the price of acetylene has dropped to the prewar level. Manufacturers of arc- and pressure-welding machines have had good business. The decrease in consumption of welding electrodes reported in 1949 was halted in 1950, but Swiss manufacturers were dissatisfied, because foreign producers were endeavoring to secure the Swiss market. Government regulations have helped domestic manufacturers who now are at full production.

The Society at its Institute at Basel and through local sections in other cities has given 28 welding courses attended by 395 students. There were six 1-week courses for students of the Basel Trade School, six 1-week courses for students in all parts of Switzerland followed by a week of practice, five special one-week courses for particular groups, five evening courses for different industries in Basel, two 22-week evening courses, and three Saturday afternoon courses for cities outside Basel.

The Swiss Welding magazine, sent to all members free, contained 234 pages in twelve issues. The welding library of the Society is very popular with members, who were glad to receive a gift of about 250 books from the Lincoln Welding Foundation. The Society undertook its usual testing work during the year, including tests of acetylene generators, torches and similar equipment, and is actively at work in the development of a dry generator for acetylene. The Society inspected acetylene installations at 1388 plants during the year, and reported completely on all accidents. The Government issued a new code on acetylene, oxygen and calcium carbide in 1950 as well as a provisional standard on gas welding rods. This tentative standard VSM 14044 for rods for gas welding steel was issued November 1950, but was formulated by a very active committee during the years 1943–46 and is based on tests at the Federal Materials Testing Laboratory.

The membership of the Society rose to 1266 at the end of 1950. The President of the Society for the term 1949–51 is Prof. Dr. P. Schläpfer.

Arcos International Prize Contest for 1953*

The administration of the firm "La Soudure Electrique Autogène S.A. Procédé Arcos," at 58–62 Rue des Deux-Gares, Brussels, Belgium, on the occasion of its thirtieth anniversary, organized an international prize contest with prizes amounting to 150,000 Belgian francs (about $3000) for original articles on electric arc welding. On Oct. 28, 1950, the Jury of Award gave only the following prizes: (*a*) a third prize of 25,000 Belgian francs, (*b*) an honorable mention of 5000 Belgian francs, (*c*) an extra prize of 10,000 Belgian francs. The Jury decided to put into competition again the remaining 120,000 francs for a new contest entitled: "Arcos International Prize Contest for 1953."

This contest is open to everyone regardless of nationality, age or title, except the members of the Jury and members of the Arcos organization. A paper may be submitted by one author or by two or more authors in collaboration, but an author's name may not appear on more than one paper. The prize money will be distributed in the following way: First prize: 50,000 francs, second prize: 30,000 francs, third prize: 20,000 francs and honorable mentions to a total of 20,000 francs. By a majority vote of $^3/_4$ of the members of the Jury, they may decide to group the prizes together or to award no prizes. The prize money will be paid at Brussels in Belgian francs and will be awarded only once. However, at the winner's request, the prize money may be transferred to a foreign country.

The papers will bejudged by a Jury—headed by Emile Duquesne, President of the Administrative Council of the Arcos firm, and consisting of the following members: one representative from each university and college in Belgium, one representative from the International Institute of Welding, six representatives at least from the different branches of industry who have an established reputation in welding in Belgium.

The subject is left to the author's choice within the limits of the following topics:

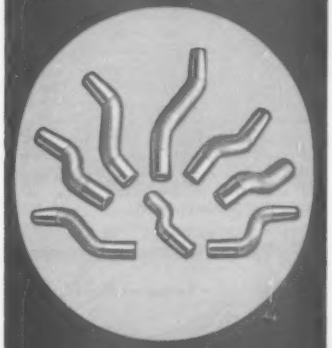
1. The metallurgy of arc welding, including electrodes, base metal or technique.
2. The nature and properties of the electric arc in air or in special atmospheres.
3. The study and measurement of shrinkage stresses and distortion due to arc welding.
4. The study of the properties of electrodes and welds, as well as of test methods.
5. The study of the characteristics of transformers and generators, of whatever type, for arc welding; their effect on the welding operation and on the properties of the welds.
6. The study of a new type of assembly or method of arc welding.
7. The study of new structural steel sections either to increase the economy of welding or to increase the safety of welded structures.

Four points will be considered by the Jury: (*a*) complete but concise treatment, (*b*) originality, (*c*) clear presentation, (*d*) must have a practical character.

Papers based on literature research and not on personal observations will not be awarded prizes. Four typed (double space) copies of the paper must be submitted. They must be in French or English; if the latter, a French translation must accompany them. Each paper must have a summary of not more than 20 lines. There must be a table of contents if the paper exceeds 15 pages.

* Abstracted by Dr. G. E. Claussen, published in Arcos, No. 120, January 1951.

For Longer Runs and Lower Costs



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Three of the copies must not bear the author's name. The fourth copy must bear his name, address and signature, and must be contained in a sealed envelope. This envelope must be placed in a larger envelope containing the other three copies. The four copies shall be sent to: Chambre de Commerce, 112 Rue de Trèves, Brussels, Belgium. The inner sealed envelope containing the fourth copy will be opened only after the results of the Jury have been issued. Papers must reach the above address not later than May 1, 1953, and shall not have been submitted to any other contest or publication. Papers that have been awarded prizes will be published in the *Arcos Review* or in a special form. Papers that have not been awarded prizes but which the administration of Arcos believes should be published in *Arcos Review*, or separately, will receive an award of 4000 francs for honorable mention. The Jury will announce its selections during the first half of November 1953.

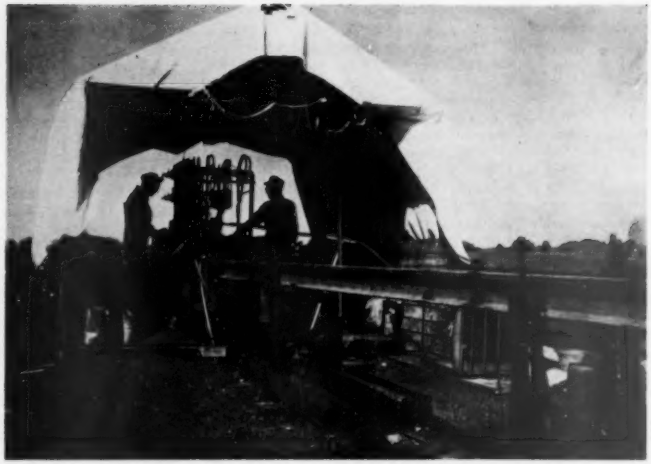

Fig. 1 Standard rail lengths are pressure-welded together in Oxweld machines to form rail lengths 1600 ft. long

World's Longest Rail?

These rails are 19,812 ft. in length—probably the longest rails in the world from which all clickety-clacks are gone. The Elgin, Joliet and Eastern Railway is the proud producer and owner of these rails which are located a few miles east of Joliet, Ill.

These superlong lengths are made by joining together standard 39 ft. rail lengths in an automatic oxyacetylene pressure welding machine. The "J," as the Elgin, Joliet and Eastern is known, welds together about 40 of the short standard rails which make 1600-ft. rails. These are next hauled out on flat cars and laid just like regular rail. Then the long lengths are welded together by a hand method to form longer rails thousands of feet in length. In the rails pictured, more than 1000 costly-to-maintain rail joints are eliminated.

The progressive "J" began laying welded rail in 1943 and by the end of 1951 it will have 90 miles of track with continuous rail—more than any railroad in North America.

Everyone wonders why the long rails do not present expansion and contraction problems. Actually, no magic has been used to remove expansion and contraction from continuous rail. As a matter of fact under temperature changes it would get

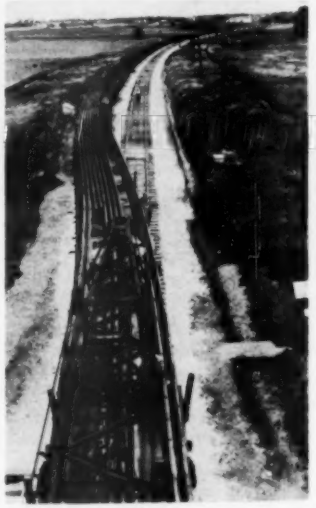

Fig. 2 Continuous rail is hauled to laying site, then laid just like regular rail

Fig 3 The 1600-ft. rail lengths are then field-welded to produce one continuous rail 19,812 ft. long

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longer and shorter if it were not for several factors. First, continuous rail is laid when the temperature is not too hot or too cold. Second, the enormous friction between rail and the ties tends to overcome expansion. Third, this frictional resistance is increased by the spikes which hold the rail down. Finally, anchors of one type or another are applied to the rail at particular points to prevent its movement. All these factors combined prevent any movement whatsoever in these superlengths of continuous rail.

Welding Saves 85 Tons of Steel in Baltimore Apartments

For the recently erected 14-story Broadview Apt. building in Baltimore, Md., 2,921,000 lb. of steel were used in the welded frame work. According to the fabricators and erectors, Vulcan Rail and Construction Co., this same building

Photo courtesy Lincoln Electric Co.

would have required 4,090,000 lb. of steel if riveted construction had been used. Welding saved 170,000 lb. or 85 tons of steel. On the original quotation for the fabrication of the building, the welding cost was approximately $30,000 less than that of riveting. Van Rensselaer P. Saxe, Baltimore engineer, designed the building as a rigid frame. This design was developed as being the best for the conditions of wind-bracing required as well as the general shape and type of structure.

Tempil° Distributor

Tempil° Corp. has added Southern Oxygen Co., Inc., Washington, D. C., as a distributor of its line of temperature indicating materials—Tempilstiks°, Tempilaq° and Tempil° Pellets.

Tempil° products have won wide acceptance in heat-dependent manufacturing operations where accurate temperature control is of importance, as in preheating for welding, heat treating, forging, hardening, tempering and casting. Tempilstiks° and other Tempil° products are now stocked by Southern Oxygen's fourteen district offices (located in Pennsylvania, New Jersey, Delaware, Maryland, Virginia, West Virginia, North Carolina, South Carolina, Tennessee and District of Columbia) and will also be available from Southern Oxygen distributors.

A Bridge Grows in Brooklyn

This bridge grows with welded roots and branches. The roadways of the Brooklyn Bridge between Brooklyn and Manhattan are being repaired and widened from 16 ft to 30 ft 11 in. The old wooden block roadways and trolley tracks on the side of the roadway are being torn out, new stringers welded in place and a roadway put down of concrete-filled Carnegie 3-in. I-beam lockgrating. The 205,500 sq. ft. of grating have been welded with $^{3}/_{16}$-in. E6010 electrodes using 20 Lincoln portable gas-engine, 300-amp. welding machines. Welding is being done by J. K. Welding Co. of Brooklyn, N. Y., for the general contractor, the Klevens Corp. When completed, the famous old bridge, built in 1883 over a period of fourteen years, will go back into service with a "new look" and six lanes of traffic. The south roadway has been completed while the north roadway is under construction.

Brooklyn Bridge Repairs

Headed for Gulf's Huge Cat Cracker

Giant section of the catalyst carrier lines for the Fluid catalytic cracker with the world's largest reactor throughput is shipped from the Jersey City Works of The M. W. Kellogg Co., refinery and chemical engineers of New York City. The section, measuring 43 ft. long and about 12 ft. in diameter including the nozzles, will be part of Gulf Oil Corp.'s new 60,000 BPD cracker at Port Arthur, Tex.

Address of the President, International Acetylene Assn.

C. E. Monlux, New York, N. Y., May 21, 1951

I am extremely happy to be here in Montreal. As most of you know, I am a citizen of the United States, but I spent three of the happiest years of my life in Canada from 1935 through most of 1938. While here I made many friends, and I always look forward to a visit to this great country with much pleasure. Since leaving Canada, I have watched with interest the continuous growth of Canadian industry. Truly, it is good to be here today.

These are extremely trying times for all of us. The future is obscure and uncertain. Our way of life is threatened, indeed, our very civilization is threatened. The pressure on individuals and industry has never been greater. There was probably never a time in our history when it was more important for everyone to do his job to the end that his industry fully and completely meets its obligations to society. As President of the International Acetylene Assn., I can say to you, without fear of contradiction, that our industry is doing just that. Since the birth of the oxyacetylene industry on our continent, in Buffalo, N. Y., in 1907, approximately 44 years ago, we have a record of which we can all be proud.

The International Acetylene Assn. was formed in 1898 prior to the inception of the oxyacetylene industry. The primary function of the Association in its early days was the promotion of safety in the use of acetylene gas, generated from calcium carbide, for lighting purposes. The Association's primary function remains the same today as when originally formed. That is, promoting safety in the use of acetylene gas, generally in conjunction with its closely allied products, calcium carbide and oxygen, in what has come to be known as the oxyacetylene industry.

The industry has grown at a continuously accelerating rate since the first acetylene and oxygen were combined on this continent in Buffalo 44 years ago to produce the hottest gas flame on earth. It has had a particularly fertile field in which to grow, for as you all know, the industrial development of the United States and Canada has not been equaled anywhere else in the world. In the early days of our industry the oxyacetylene process was used largely as a repair tool. Today it is a process essential to industrial production, with a wide variety of applications ranging from the steel producer's mill to the fabrication of countless items made of all types of metal.

It is worthy of note that our industry, since its inception, has grown at a faster rate than the industrial productive capacity that it serves. Particularly is this true during the last twelve years. This has been due largely to the foresight and willingness of the industry to spend a substantial portion of its earnings in research and development, that has resulted in bringing many new and profitable applications of the process to industry.

I am particularly proud of our record during World War II, and I am sure all members of the industry share my feeling. The requirements of the rearmament program in the early 40's and the war which followed, that were placed upon this industry and that were fully met by the industry, were truly astounding. For example, the production of dissolved acetylene gas in the United States and Canada from 1939 through the peak war production year of 1944 increased approximately 400%. The production of acetylene's partner, oxygen, during the same period increased slightly more than 400%, and the production of calcium carbide, from which acetylene gas is generated, increased in like proportion. During the same period, steel production in the United States and Canada increased slightly less than 70%. It is doubtful if the increased demands for any critical materials during this period were as great as those met by the oxyacetylene industry. The demands placed upon the industry during the war years for military and civilian purposes were fully met by the industry with a minimum amount of fanfare and practically no use of Government money. I feel we can be proud that our nations and all users in them had all the oxygen, acetylene and calcium carbide that were actually needed during that extremely critical time.

In developing and expanding the industry, it is necessary for us to work closely with various government regulatory bodies. Acetylene gas is a flammable gas. It is important, therefore, that its usage conform to safe practice. The cooperation that exists between the industry and government agencies has been of the highest order. This has been extremely helpful to us in meeting demands for our product, and we like to think that through our Association we have been helpful to these regulatory bodies.

It seems appropriate to remind you that the use of the oxyacetylene torch or blowpipe is an economical, time-saving production tool. Those of you in industry readily appreciate that the process has contributed in no small measure to the tremendous increase in production of almost every item made of metal, from the steel producing plant itself to all fabricated metal articles; including ships, locomotives, automobiles, airplanes, tanks, all types of war material, such as rockets and jet propulsion engines, as well as thousands of peacetime items. Without the process, the production records made during and since World War II would have been virtually impossible.

Over the past several years, the cost of acetylene and oxygen to the consumer has risen but a fraction compared to the increased cost of other material and labor. At this critical time in our history when materials and labor are rapidly approaching conditions of short supply, our industry has an added responsibility to have not only an adequate supply of oxygen, acetylene and calcium carbide available but also to introduce and encourage their use in new and old applications.

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consumption of the three major products in our industry decreased for a short period. However, when the conversion from wartime production to peacetime production was completed, consumption figures began to climb again, well above the prewar figures. Indeed, the demand for our products during the conversion to peacetime production remained above the prewar demand. We are again engaged in a rearmament program and facing the possibility of a third world war. The demands upon our industry today are greater than they were during the peak years of World War II. This is true of all three major products: oxygen, calcium carbide and its end product, acetylene gas. The use of acetylene gas in the chemical industry is an added factor in its large present-day usage. This demand since World War II has been very large and will undoubtedly continue to increase. A number of you here today, and particularly you Canadians, are no doubt familiar with the importance of acetylene in the chemical and plastic industries, for as you know, you have just a few miles from here, at Shawinigan Falls, a very large chemical operation based largely on the use of acetylene gas. Acetylene's partner, oxygen, is also being used in extremely large quantities in the chemical industry as well as for metallurgical purposes as distinguished from the normal oxyacetylene process in the production of steel.

During the last three years, industrial production capacity on this continent has been increased at a phenomenal rate. Capital expenditures for new facilities for the three years, 1948, 1949 and 1950, have been at the rate of about 16 billion dollars a year for the United States and Canada. Estimates for 1951 are in the neighborhood of 23 billion dollars. Plans for this year and for 1952 call for the building of many, many new production facilities as well as the development of raw material sources. The development of iron ore bodies in Labrador is now under way and marks a major Canadian contribution. I am proud to state authoritatively that the oxyacetylene industry has carefully surveyed the planned expansion in the United States and Canada and is now in the process of providing additional production of calcium carbide, acetylene gas and oxygen to fully meet the demands that will be placed upon us. Again let me say, this expansion is being financed by private capital. I am confident that we will meet these demands and that the rearmament program will not suffer for lack of our products. I am equally confident that we will meet any necessary demands that may be put upon us in the event of total war—which God forbid.

Annual Meeting
American Welding Society
Book-Cadillac Hotel
Detroit, Michigan
Week of Oct. 15th

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PERSONNEL

E. H. Roper Appointed Manager Airco General Technical Sales Dept.

Air Reduction Sales Co., a Division of Air Reduction Co., Inc., has announced the appointment of Edward H. Roper as Manager of the General Technical Sales Dept.

Joining Air Reduction in 1936, Mr. Roper served in various capacities in the General Technical Sales Dept. and was appointed Assistant to the Manager of that Department in 1944. Four years later he became Assistant Manager of this department whose function it is to assist nation-wide users of Airco products and processes in their proper applications.

During the war years, he was an instructor for aircraft welding classes administered by the University of the State of New York.

E. H. Roper

Mr. Roper attended the Buckley School in New York, The Taft Preparatory School in Watertown, Conn., and in 1932 received his Bachelor of Science Degree in Mechanical Engineering from the Sheffield Scientific School, Yale University. His early engineering experience included such diversified fields as installation of Diesel-electric equipment in California and operation of petroleum equipment in Aruba, N. W. I.

He is a licensed engineer in the State of New York and for many years has been an active member of the American Society of Mechanical Engineers and the AMERICAN WELDING SOCIETY. He has presented technical papers before various industrial societies and is a co-author of *Oxygen Cutting*, a recent textbook on oxyacetylene cutting.

Eutectic's President Appointed to N.A.M. Research Committee

The appointment of Rene D. Wasserman, Director of Research and President of Eutectic Welding Alloys Corp., Flushing, N. Y., to the Research Committee of the National Association of Manufacturers was announced by Earl Bunting, Director of N.A.M.

R. C. Freeman Named Manager

Raymond C. Freeman has been named manager of the General Electric Co.'s Welding Divisions at Fitchburg, Mass., according to a recent announcement by Nicholas M. DuChemin, general manager of the Company's Small Apparatus Division.

Concurrently, Mr. Freeman appointed Alanson U. Welch to succeed him in his former position as manager of engineering of the Welding Divisions.

Until his appointment as manager, Mr. Freeman was acting manager, having assumed the responsibilities of A. F. Vinson, former manager, last April. Mr. Vinson left at that time to attend the Advance Management Program's Business Training Course at the Harvard Graduate School of Business Administration, and has since been appointed manager of Employee and Community Relations, Small Apparatus Divisions.

A graduate of the University of Minnesota in 1929, Mr. Freeman joined G-E the same year as a student engineer on the Company's Test Course at Schenectady. Shortly thereafter, he was transferred to the company's Lynn, Mass., plant where he was assigned to the Motor Design Engineering Division. While at Lynn, he attended the Boston University Graduate School of Business Administration.

R. C. Freeman

In 1937 Mr. Freeman became section engineer in the G-E Welding Divisions then located at Lynn, and in 1946 he assumed the post of division engineer of d.-c. welders at Fitchburg.

He was named manager of engineering of the Welding Divisions two years later, the position he held until his present appointment.

Mr. Freeman, who holds a patent on arc welding control, is a member of National Committee of Electric Welding of the A.I.E.E., a member of the board of directors, Worcester Section, of the AMERICAN WELDING SOCIETY, and is active on the Committee on Electric Welding and the Committee on Low Voltages of the American Standards Association.

Mr. Freeman is holder of the Coffin Award, the highest recognition the General Electric Co. can bestow an employee.

S. D. Baumer Appointed Vice-President Airco Equipment Mfg. Division

Air Reduction Co., Inc., has announced the appointment of S. D. Baumer as Vice-President of the Airco Equipment Mfg. Division.

S. D. Baumer

Joining the Airco General Technical Sales Dept. in 1941 as steel mill specialist, Mr. Baumer was appointed assistant manager of that department in 1944 and manager in 1948.

Mr. Baumer has long been an active member of the Association of Iron and Steel Engineers, the AMERICAN WELDING SOCIETY, and the Iron and Steel Institute.

A native of Johnstown, Pa., Mr. Baumer spent a number of years in the cast-iron radiator and boiler field before joining the Bethlehem Steel Co. at the Johnstown plant where he was employed in various capacities until 1941 when he joined Airco.

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HASTELLOY Alloy C Is Easy To Apply:

Alloy C rod can be easily applied to the worn contour and part lines of old forging dies. Preheating is seldom necessary except to speed welding of very large dies. The rod can be applied to any of the common die steels by arc welding.

Deposits Are Machinable:

When deposited, HASTELLOY alloy C has a hardness of about 200 Brinell. It can be machined by any of the common diesinking tools. Grinding is not necessary.

Peening Is Eliminated:

There is no need to peen or hammer a HASTELLOY alloy C deposit. Deposits work-harden in service to from 325 to 375 Brinell and have excellent resistance to chipping and spalling.

For further information on rebuilding worn forging dies, get in touch with the nearest Haynes Stellite Company district office. Ask for a copy of the new "Haynes Hard-Facing Manual," which tells how to apply HASTELLOY alloy C and many other HAYNES hard-facing rods.

HAYNES TRADE-MARK *alloys*

"Haynes" and "Hastelloy" are trade-marks of Union Carbide and Carbon Corporation.

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A. F. Vinson Appointed Manager

Arthur F. Vinson has been appointed manager of employee and community relations of General Electric's Small Apparatus Divisions with headquarters at Lynn, Mass., according to an announcement by Nicholas M. DuChemin, general manager of the divisions.

A native of Plainfield, Ill., Mr. Vinson was graduated from Michigan State College in 1929 with a B.S. degree in electrical engineering. He then joined G-E on the company's Test Course at Fort Wayne, Ind. He held successive positions as process engineer, d.-c. motor section head and inventory control supervisor.

In 1939 he was named assistant production manager at the Fort Wayne Works, a position he held until 1945, when he transferred to Schenectady, N. Y., as assistant production manager of the company's Apparatus Dept. He was appointed chairman of the committee in charge of the former Welding Equipment Divisions in 1947 and a year later became manager of the Welding Divisions at Fitchburg, Mass.

Mr. Vinson recently completed the Advanced Management Program of Harvard University's Graduate School of Business Administration.

TWECO CABLE CONNECTORS

—"SOL-CON" (solder type)
—"MEC-CON" (mechanical)

Quick - detachable connectors Add on cable. Take off cable. Attach holder whip cables. Split male plug permits adjusting spring tension for electrical contact. Two sizes, Sol-Con; three sizes, Mec-Con for #6 through 4/0 cable.

Tweco "Sol-Con" and "Mec-Con" plugs fit the female part of Tweco Terminal connectors for quickly connecting cables to the welding machine and to switch polarity. They are COMPANION ITEMS.

See Your Welding Supply Distributor

Tweco PRODUCTS COMPANY

TWECO PRODUCTS

Boston at Mosley St.
WICHITA, KANSAS

Davis Receives Degree

A. F. Davis was recently honored by the receipt of the degree of Doctor of Science. Below are the comments of William Morgan, the Commencement Marshal at Mt. Union College in Alliance, Ohio, when presenting him for the degree.

"President Ketcham, as a representative of the faculty of the College, I wish to present Mr. Alton Frank Davis. Mr. Davis was born and educated in this area. After graduation from the Alliance High School, he entered Mount Union College where he studied for two years. He interrupted his college training program to serve two years in the Engineering Department of the City of Alliance. He resumed his education at the Ohio State University and was graduated with a degree of Bachelor of Engineering in Electrical Engineering in 1914.

"Upon his graduation from Ohio State, Mr. Davis entered the employ of The Lincoln Electric Co. of Cleveland, where through the intervening years he has served in several capacities. At present he is a Director, Vice-President and Secretary of the Company as well as the Secretary of The James F. Lincoln Arc Welding Foundation.

"His associates have felt in him a source of inspiration and an inexhaustible fountainhead of ideas. Because of Mr. Davis' interest in the dissemination of knowledge, the developments of the science of welding have been made available not only to the industrial field but to the public as well. Through his own personal efforts and through the Foundation, extensive libraries on welding theories and practices have been placed in strategic positions for use.

"He is editor of *The Procedure Handbook of Arc Welding Design and Practice*, now in its ninth edition with a total distribution of over one quarter of a million copies, and under his guidance the Foundation has published many other important works.

"He has promoted progress in welding through the A. F. Davis Welding Awards for undergraduate engineers.

"Through his years of accomplishment in his own field, Mr. Davis achieved an understanding of people and human relationship which has given him a steady course by which to steer. His faith in his fellow man has made him a champion of the individual and a forthright spokesman of the dignity of hard work.

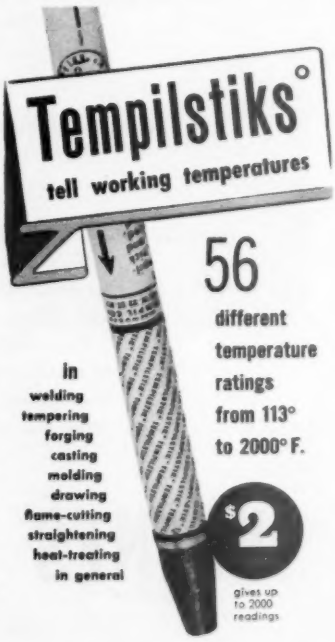
"President Ketcham, on behalf of the faculty of the College, I have the honor to present to you Alton Frank Davis to receive the degree, Doctor of Science."

Employment Service Bulletin

Positions Vacant

Draftsmen for rapidly expanding Steel-Weld Fabricating Division, experienced in design and detail of Steel Weldments with knowledge of Structural Steel Design. Apply by letter only, stating age, experience, technical training and salary desired. Write The R. C. Mahon Co., Chief Engineer, Steel-Weld Division, P. O. Box 4666, Detroit 34, Mich.

V-255. Graduate Electrical Engineer with two to four years of experience, with a working knowledge of electronic instruments for the development of resistance-welding machinery.


Tempilstiks®
tell working temperatures
56
different temperature ratings from 113° to 2000° F.
in welding tempering forging casting molding drawing flame-cutting straightening heat-treating in general
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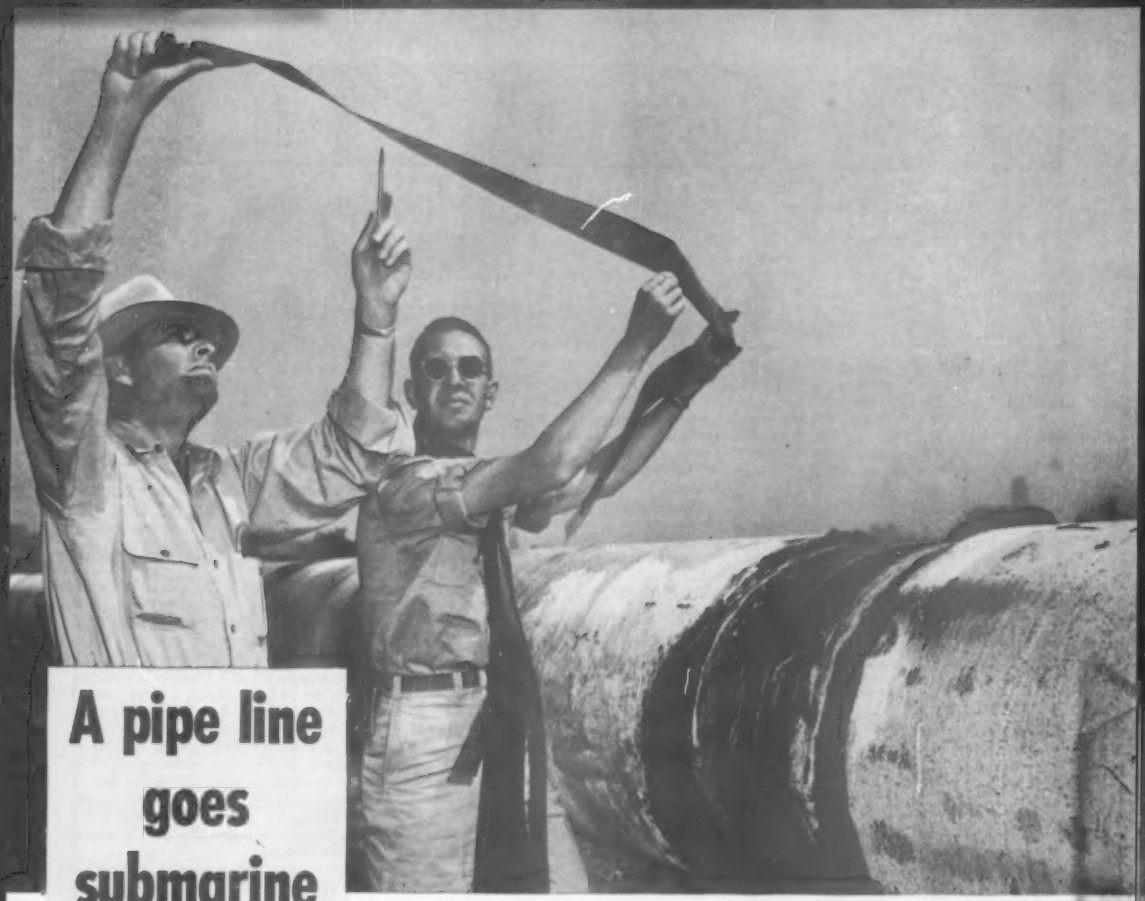
gives up to 2000 readings

Tempil® corp.
134 WEST 22nd STREET, NEW YORK 11, N. Y.



Inspectors studying radiographs of completed welds in the 26-inch-diameter, 1¼-inch-thick steel pipe.

A pipe line goes submarine and Radiography proves each weld

NATURAL GAS from Texas makes its final plunge into New York City through a 4800-foot pipe line laid under the bed of the Hudson River. Each joint was welded. And with 450 lbs. p.s.i. inside and the pressure of silt and 90 feet of water outside, these welds had to be sound and set for a long life. To make sure, the contractor had radiographs made of every joint.

This is how Radiography helps do important jobs well. It puts a valuable O. K. on welds. It helps build reputations for consistently good work.

Wouldn't you like to know how it is helping to increase business and improve production for others? Your x-ray dealer will be glad to tell you. Get in touch with him.

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Radiography...

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Kodak
TRADE-MARK

NEW PRODUCTS

Bronze Welding Rod

EutecRod 148FC, a new bronze welding rod featuring an extra-thin initial "tinning" action, has been released by Eutectic Welding Alloys Corp. Claimed by the manufacturer to be capable of eliminating prewelding preparations required by conventional rods, new EutecRod 148FC reportedly flows there directed without extensive chamfering, even on butt joints where necessary.

Each rod is covered with a new type of specially developed flux coating yielding full strength joints on old, corroded and dirty cast iron. Tensile strength is listed up at to 55,000 psi. and a Brinell hardness of 75–120. It is claimed to be the first bronze welding rod which can be used in chamfer joints as well as square butt and lap joints.

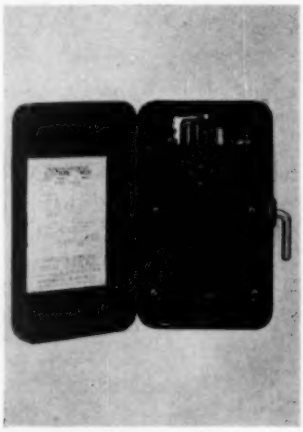
Complete specifications and technical data are available upon request from Dept. TIS, Eutectic Welding Alloys Corp., 172nd St. and Northern Blvd., Flushing, N. Y.

Short Interval Electronic Timer

Photoswitch Electronic Timer Type 30CR3 is designed to meet requirements for accurately controlled short interval timing. It has a timing range of from 3 to 120 cycles, and fulfills the specifications of N.E.M.A. class 1A nonsynchronous timers. In addition to its many general-purpose timing applications, Type 30CR3 is recommended for spot welders and is applicable to manual-, air- or motor-operated welding equipment requiring either beat or nonbeat operation. It is extensively used as well for automatic filling operations in the food and drug industries, the control of punch presses and other machine tools, and conveyor control.

Many features of particular importance in short interval timing and to the welding fields are incorporated in this timer. The timing adjustment is calibrated for any interval from 3 to 120 cycles and the accuracy throughout this range is within 2%. The timing adjustment is located on a panel inside the housing thus providing a tamperproof setting. The timer may be used with either a 115 or 230 v. a.-c. supply. By simple selection of terminals on the terminal panel, the timer will provide "beat" or "nonbeat" operation (control from momentary or sustained contact switch). The terminal panel is provided with a bakelite dead-front eliminating the danger of an operator contacting the terminals when setting a timing interval.

Combinations of Timer Type 30CR3 are used when it is desired to control other portions of the welding cycle, such as the squeeze, heat, cool, "on" and "off" periods. Photoswitch, Inc., 77 Broadway, Cambridge 42, Mass.



Electronic Timer

Tempilaq° 2000

Tempil° Corp. of 132 W. 22nd St., New York 11, announces the development of Tempilaq° to indicate 2000° F., thereby extending the high temperature range of Tempilaq° above the 1950° F. level hitherto available.

Tempilaq° can now be obtained in 12- or 13-degree steps from 113 to 400° F., and in 50-degree steps from 400 to 2000° F.

Tempilstiks°, the crayon form of temperature indicator, and Tempil° Pellets are available in similar intervals covering the same range of temperatures from 113 to 2000° F. In addition, Tempil° Pellets

can also be supplied for temperatures above 2000° F. in 50-degree steps to 2500° F., inclusive.

Self-Centering Rotating Clamp

The Philadelphia Division, Yale & Towne Mfg. Co., has perfected a new hydraulically operated clamp for industrial fork trucks, which enables bales, bins, drums and miscellaneous containers to be picked up and transported on the center line of the truck. Conventional clamps and grabs of a similar nature do not have synchronized movement of arms in opening and closing, making it difficult to carry loads, unless the truck is lined up *perfectly* with the center line of the load. The off-center loading resulting from these clamps makes the truck unstable, particularly when the clamp and load are rotated.

When used with a rotator, the clamp does not creep off center. Loss of pressure grip in arms is minimized. A vari-

Self-Centering Rotating Clamp

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There's hardly a METAL-JOINING problem that EUTECTIC WELDING ALLOYS *hasn't a better solution for!*

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Improve machinability?

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. . . easier and faster to use than conventional grades of welding rods . . . yet yielding vastly superior results and lasting satisfaction . . .

ANSWER EVERY METAL JOINING NEED

Over 78,000 users now specify genuine EUTECTIC Low Temperature WELDING ALLOYS and EUTECTOR Fluxes wherever stronger, better joints are desired . . . on ALL metals—cast iron, alloy steels, aluminum, copper and nickel alloys, die castings, overlays, etc.

It will pay YOU to keep fully posted on the selection of alloys available and the advantages of each for the particular jobs you face . . . for torch . . . arc . . . furnace . . . induction heating.

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Yours for the asking: EUTECTIC's National Defense Manual Series—"Manual of Welding Engineering & Design"; "Manual of Tool & Die Salvage"; etc. Also profusely illustrated technical literature complete with specifications, case histories, etc.

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In metal-joining, the "proof of the pudding" is in the *demonstration*, not in the advertising claims. That is why we keep saying: "Make us prove it!" We gladly offer a FREE Consultation-Demonstration right in your own shop!

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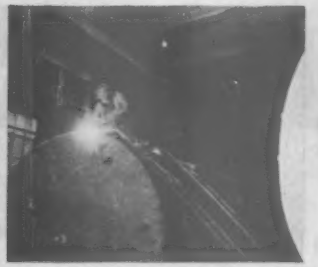

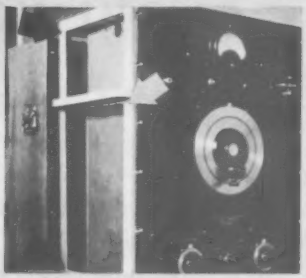

DEFENSE CONTRACTORS

building aluminum structures should have the help of their . . .

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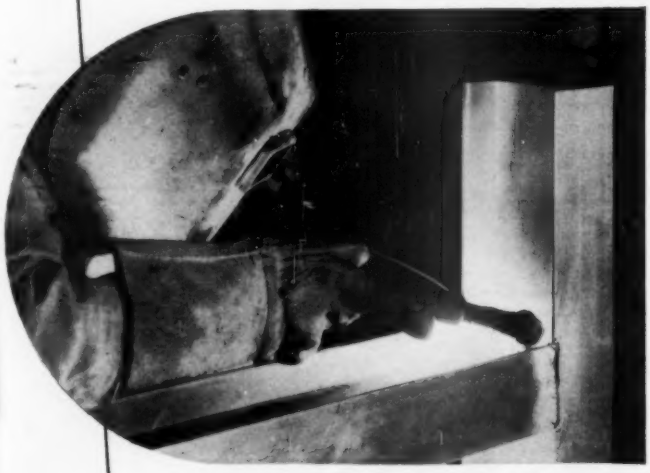
He makes available to you Alcoa's authoritative technical library . . . 4 specialized training films on aluminum welding, plus a profusely illustrated 135-page welding handbook. You'll find your Alcoa Distributor listed under "aluminum" in your classified phone book. Or write to ALUMINUM COMPANY OF AMERICA, 1944H Gulf Bldg., Pittsburgh 19, Pennsylvania.



Dependable welds are quickly and economically made on aluminum structural members. Ask your Alcoa Distributor.

ALCOA FIRST IN ALUMINUM

able clamping pressure permits handling of any type load, such as fragile cartons, heavy containers, bales and boxes.

The self-centering arms have an inside opening range from 17 in. minimum to 66 in. maximum. The clamp will handle loads up to 6000 lb. and can be installed on gasoline or electric trucks.

Heliarc Welding Stainless Steel Cabinet Doors

A lightweight, HW-9 Heliarc torch is being used here to weld the stainless steel frame of a cabinet door. The door is fabricated from 18-gage, type 302 stainless steel. The frame sections are tack-welded first, then fully welded and finished

by grinding. The Low-Temp. Co. of Jonesboro, Ga., manufacturer of the doors, reports that the HW-9 torch is used because it is lightweight and since it is air-cooled, needs no provision for water cooling. This air-cooling feature, the company says, makes the HW-9 suitable for outside-the-shop assembly work.

Spot Welding & Soldering Machine

Joyal Products, Inc., 11 Hill St., Newark, N. J., announces the availability of its new Resistance Spot Welding & Soldering Machine (Model 1000 WV, or 2000 WV—a. c. only), equipped with timer. This machine speeds production, cuts costs, eliminates shrinkage in the manufacture of instruments and is invaluable to the manufacturer of small products and jewelry. It solders or welds in less than a second.

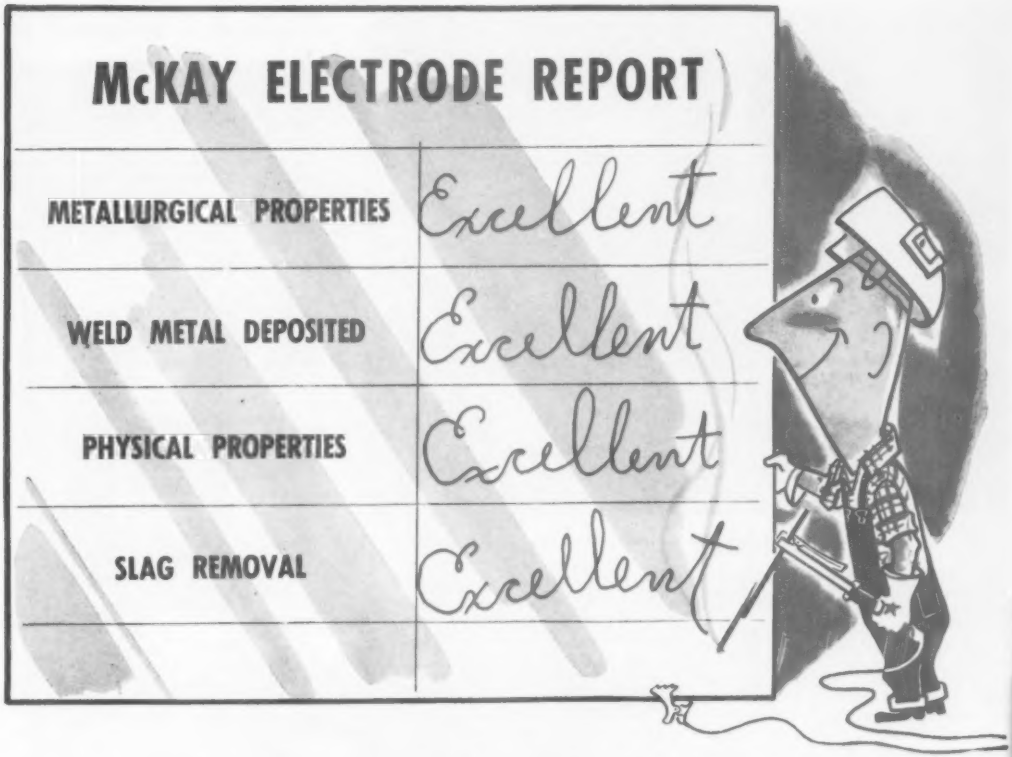
Also, this machine silver solders, soft solders and spot welds precious and dissimilar metals. It spot welds steel parts up to $^{3}/_{32}$ in. in thickness. It will solder brass up to $^{1}/_{8}$ in. in thickness as well as sterling silver and other precious metals.

Model 1000 WV: 110 v. a. c., 9 amp.

Model 2000 WV: 220 v. a. c., 10 amp.—equipped with water-cooled electrode holders.

Dimensions: 10 in. long by 11 in. deep by 10 in. high, plus control box 4 in. high.

Model 1000 WH, or 2000 WH, a. c. only, is the same as Model 1000 WV or 2000 WV, except that this machine is equipped with horizontal electrodes to handle jobs such as the soldering of a plastic decoration to a semiprecious tie clasp.



The Case of the Right Report

A perfect rating every time—all the time . . . that's the performance record of every McKay Electrode. Experienced welding men know that uniform Electrodes, with fully controlled properties, are a "must" for structurally sound weldments.

McKay Electrodes are formulated to provide metallurgically sound weld-metal with specific physical properties. Absolute control in each manufacturing operation assures uniformity in every Electrode in the McKay line.

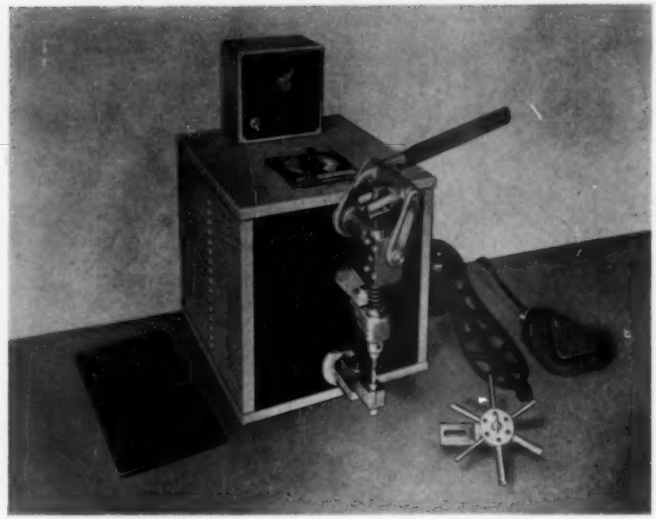
* * * * * * *

Our Technical Staff will appreciate the opportunity to recommend the Electrodes best suited for your particular needs and send you samples for "on-the-job" tests.

McKAY
ARC-WELDING
ELECTRODES
For MILD, STAINLESS & ALLOY STEELS

HAVE YOU HEARD ABOUT THE NEW McKAY 16 (AWS E-6020) ELECTRODES?

THE McKAY COMPANY
406 McKAY BUILDING
Pittsburgh 22, Pa.



Spot Welding and Soldering Machine

An automatic cutoff timer regulates soldering time. Heat control with eleven adjustments determines correct heat for the job. When dials are set, uniform soldering time, heat and holding pressure on the electrodes are maintained, regardless of how long the foot switch is held down. Thus, all chance of work burning and consequent shrinkage is eliminated.

For additional information and catalog material on the new Joyal Resistance Spot Welding & Soldering Machine, please write to Joyal Products, Inc., 56 Belmont Ave., Newark 3, N. J.

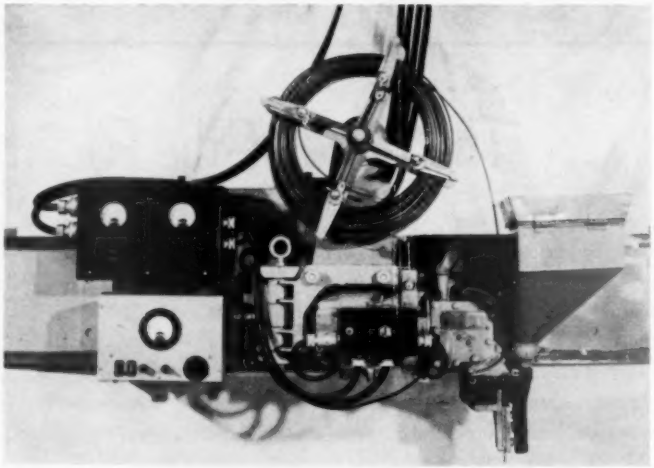
High-Speed, Accurately Controlled "Unionmelt" Welding Machine

Uniform welding of straight-line seams in light to heavy plate can be done at high speeds with the new UE-48 welding machine designed by Linde Air Products Co., a Division of Union Carbide and Carbon Corp., for "Unionmelt" welding in permanent production installations.

The UE-48 machine consists of Linde's new CM-48 Side Beam Carriage, a UE welding head, a small rod reel, a Unionmelt feed hopper and controls. The equipment is mounted on the steel frame of the carriage, which rides a cold-rolled steel track. A DS "Unionmelt" welding head can also be used with this carriage, and the machine is then designated the DS-48.

Welding conditions for a particular job can be set into the control mechanism of the machine before it is put into operation. The welding current, the carriage speed, the welding voltage and the "Unionmelt" material flow all can be adjusted before welding is begun.

An inherently accurate electronic governor controls the speed of the carriage. This control permits a stepless speed range of from 3 to 200 in. per minute. The rate of speed can be preset by a meter, and the carriage will move immediately at that speed when started. The speed rate can also be changed while the carriage is in motion.



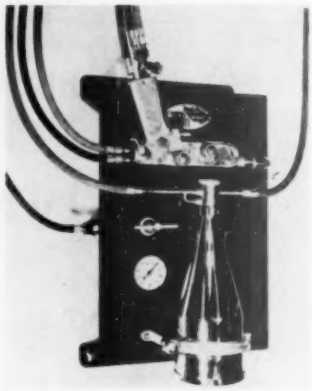
High Speed "Unionmelt" Welding Machine

After the controls are adjusted for the desired welding conditions, the operator switches the machine "on" and it proceeds to weld without further attention. This frees the operator to unload and load the welding job. It also reduces human error and effort, and results in the production of identical welds.

A wide variety of work can be handled with the UE-48 machine. Metal from 16-gage to $1^1/_2$ in. thick can be welded with a single pass. The head can be positioned at right angles to the track, or parallel to it as shown in the accompanying illustration. It can be adjusted to make any type of butt or fillet weld.

Colmonoy Spraywelder

Wall Colmonoy Corp. announces a new model of their Spraywelder. The Sprayweld Process consists of applying uniform overlays of Colmonoy Hard Facing alloys using metallizing procedures, and then subsequently bonding the overlay to the base metal.



In addition, the Spraywelder can be used to apply metal powder castings such as copper, brass, stainless, aluminum and zinc.

The Model B Spraywelder incorporates many new features: Lighter weight greater capacity air filter, more positive air and powder control valves, new trigger mechanism—finger-tip control with lock for continuous or intermittent spraying and increased cooling chamber in head insures steadier operation and longer tip life.

TIMELY HELP FROM TITANOX RESEARCH:

NEW

TITANOX-TG

IMPROVES WELDING ROD COATINGS

The greater arc stability of welding rod coatings having *higher* and *more uniform* titanium dioxide content is readily achieved with new, non-pigmentary TITANOX-TG. Unlike pigmentary grades of titanium dioxide, this new product has a remarkably low content of phosphorus, sulfur and volatile metals including zinc and antimony. In comparison with pigmentary titanium dioxide, TITANOX-TG requires much less silicate binder. Thus, not only can the TiO_2 content of the coating be appreciably increased but also accurately controlled through high purity.

This highly purified titanium dioxide is free-flowing, non-sticking and non-balling. It will contribute to faster and more economical production, particularly when dry blending is employed. We shall be glad to help you adapt TITANOX-TG to your titanium coated electrodes. Write today to our Technical Service Department. Titanium Pigment Corporation, 111 Broadway, New York 6, N. Y.; Boston 6; Chicago 3; Cleveland 15; Los Angeles 22; Philadelphia 3; Pittsburgh 12; Portland 9, Ore.; San Francisco 7. In Canada: Canadian Titanium Pigments, Ltd., Montreal 2; Toronto 1.

8855

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Subsidiary of NATIONAL LEAD COMPANY

Arcair Torch

The Arcair Co., P. O. Box 1792, Station A, Bremerton, Wash., has produced a gouging and cutting torch which operates on an ordinary d.-c. welding machine and a compressed air line.

It removes defects in castings or forgings, cleans root of welds, removes welds, and grooves, cuts or bevels mild steel, stainless steel, hard alloys, brass bronze, Monel, cast iron or any other metal.

The manufacturer states that it operates five times as fast as chipping. Gouges a $^{3}/_{8}$-in. groove at over two feet per-

minute. The depth of cut is easily regulated and welding slag does not deflect or hamper the cutting action. No oxygen or fuel gas required. The same man that does the welding can also operate this torch. Though not much larger than an arc-welding electrode holder, it contains an air control valve and rotating nozzle which permits changing the electrode angle to suit the job, but maintains the jet in perfect alignment. No gas cylinders or regulators are necessary. It can be used anywhere it is possible to weld. Operates in spaces too restricted to accommodate a chipping hammer or oxygen gouging torch. Requires no difficult adjustments for use on different materials. Resulting surface is clean and smooth. Welding or brazing can be done without further grinding or cleaning.

NEW LITERATURE

Quantometer

The "Quantometer," a direct reading spectrometer capable of automatically giving complete and accurate analyses of brass and bronze alloys in a few minutes, is featured in the booklet "Control—The Key to Improvement in Quality Products," just published by Titan Metal Mfg. Co., Bellefonte, Pa. Other modern control methods used in the fabrication of Titan brass and bronze rods, forgings, die castings, welding rods and wire are also illustrated and described.

Standard Manual on Pipe Welding

The preparation of this book is the result of more than six years of intensive work including hundreds of tests and much research work, and has been published in response to requests from architects, engineers and piping contractors, for an up-to-date and authoritative treatment on welded piping design and installation practices.

Every effort has been made to present what is today the most reliable standards, practices and theory in pipe welding. To provide the proper background of varied industrial experience, the Editorial Committee consisted of representatives of Piping Contractors, Fabricating plants, Trade and Technical Associations allied to the industry, and manufacturers of pipe fittings and of welding equipment.

The book has 506 pages, is profusely illustrated and is priced at $7.50 per copy. A discount of 10% is allowed on orders for six or more copies. It is a practical book—one that will certainly prove valuable in the hands of those interested in modern pipe welding design and installation.

Heating, Piping & Air Conditioning Contractors National Assn., Suite 1401, Rockefeller Center, 1250 Sixth Ave., New York 20, N. Y.

Low-Temperature Brazing

Handy & Harman, 82 Fulton St., New York 38, N. Y., has issued an attractive four-page folder on Low Temperature Brazing, News #54. Copy available on request.

Heliarc Welders

A.-C. Arc Welders for "Heliarc" Welding, Miller Electric Mfg. Co., Appleton, Wis., describes complete line of transformer type welder for all applications of the "Heliarc" process, with charts, specifications and recommendations for automatic control panels, and "Heliarc" spot welder.

Booklet on Cast-Weld Construction

Valuable data on technical developments in the field of cast-weld construction, citing numerous examples of impressive metals conservation, production economies, improvements in functional design and other engineering gains, is being made available in booklet form by the Steel Founders' Society of America.

Based on detailed technical papers presented at the Society's national Technical and Operating Conference, the booklet comprises a reprint outlining numerous practical examples of leading steel foundries' effective application of proved cast-weld techniques.

Including 16 illustrations typical of product engineering gains discussed in the various papers, the text runs to nine pages and incorporates detailed information on improved cast-weld principles and related redesign considerations.

Copies may be obtained by writing to F. Kermit Donaldson, executive vice-president, Steel Founders' Society of America, 920 Midland Bldg., Cleveland 15, Ohio.

New Reynolds Book

Birth and growth of the second largest source of aluminum in the United States is outlined in a new book *Reynolds Aluminum and the Company That Makes It*, just issued by Reynolds Metals Co.

This 48-page, $8^{1}/_{2}$- x 11-in. book also contains details on Reynolds production facilities, products, fields served and other information designed to give a clear picture of the company and its operations.

Copies of the book are available without charge. Address your request to Reynolds Metals Co., 2500 S. Third St., Louisville, Ky.

Galvanizing (Hot-Dip)

This book by Heinz Bablik is the third edition of a modern study of the metallic rust prevention process that has found the widest application.

The author's guiding thought in this, as in his other works, is that theory is the best guide to practice. Both the practical and the theoretical aspects are emphasized in Professor Bablik's discussions of such topics as scale, pickling, fluxes, and galvanizing.

The close connection between theory and practice evident in "Galvanizing (Hot-Dip)" can be traced to the fact that the author, as a lecturer in the Technical University of Vienna, is on one hand in close touch with science, and on the other, is manager of his own galvanizing factory.

Welding is also covered. The book consists of 502 pages and is published by John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y. Price $10.

THAT P&H AC WELDER LOOKS GOOD TO ME, JIM. WE CAN GET IT OFF THE FLOOR —AND HAVE MORE ROOM TO WORK!
THAT'S RIGHT, BILL— AND WITH CONTROL AT THE WORK WE GET MORE DONE, AND DO IT BETTER!

Save floor space, cut welding time for more production at lower cost

. . . . use P&H AC Arc Welders with exclusive Dial-lectric remote control

Give yourself more room for your production needs. Mount your P&H Welder off the floor, out of the way.

Dial-lectric remote control lets you do this. Your operator can turn the heat on *at the work*. It also cuts down his "walking time" . . . turns it into *welding* time for increased output.

Besides saving space P&H Dial-lectric control eliminates cores, coils, sprockets, gears and other moving parts that cause excessive maintenance and downtime.

P&H AC Welders are available in a full range of sizes up to 625 amps. See your P&H representative or distributor for full details on how this outstanding welder can save you time and money.

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WELDING DIVISION
4551 W. National Avenue
Milwaukee 14, Wis.

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Specialized Training

Metal Welding Fabrication

1 week to 18 months

Harnischfeger Welding Training School

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HARNISCHFEGER CORPORATION
Welding Division
4551 WEST NATIONAL AVENUE
MILWAUKEE 14, WISCONSIN

abstracts of CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25c from the Commissioner of Patents, Washington 10, D. C.

2,552,873—Cutting Torch—Elmer H. Smith, Minneapolis, Minn., assignor to Smith Welding Equipment Corp., Minneapolis, Minn., a corporation of Minnesota.

This patented cutting torch includes a head having an enlarged bore therein open at one end and a relatively smaller bore axially aligned with the larger bore. A spring-pressed tubular sealing element is in the smaller bore with one end in communication with a supply of high-pressure cutting gas, and a torch tip is provided which has a cylindrical end portion that is slidably received in the larger bore and has a suitable cutting gas passage extending lengthwise therethrough and in communication with the tubular sealing element when the tip is secured in the torch head. The torch tip also has a plurality of preheating fuel passages therein and means are provided for delivering fuel gas to the preheating fuel passages. A seat is provided at the inlet end of the torch tip for engaging the adjacent end of the tubular sealing element to prevent leakage of the high-pressure cutting gas into the preheating fuel passages when the torch is in operation.

2,553,609—Weldable and High-Temperature Resisting Hard Alloys of Cobalt and Iron Base—Max Schmidt, Kapfenberg, Austria.

Schmidt's new alloy comprises special percentages of carbon, silicon, chromium, tungsten and molybdenum. The remainder of the alloy is substantially all cobalt and iron, with the iron content amounting to at least 35% and not exceeding 80% of the total sum of iron and cobalt contents.

2,553,899—Windshield for Welding—Oscar E. Dempsey, Tulsa, Okla., assignor to Dempsey Pump Co., Tulsa, Okla., a corporation of Oklahoma.

This special welding windshield is for use on pipelines and comprises a plurality of segments of duplicate arcuate sections adapted to surround the pipe in face-to-face relationship. Each of these sections may comprise a plurality of segments, each of which has a flat portion in substantial alignment with the longitudinal axis of the pipe, and arcuate means connecting with and extending outwardly from such portion. Pliable rubber means are secured to each of the sections and are positioned in overhanging relation to the outer edge of the arcuate part of the segments so that such pliable rubber means surround the pipes and abut on duplicate rubber means on a duplicate arcuate section of the windshield. Thus a continuous shield is provided around the pipe which shield permits ingress through the pipe at any circumferential point covered by the shield.

2,553,947—Welding Jig for Car Underframes—Tolbott G. Shipley, St. Louis, Mo., assignor to American Car and Foundry Co., New York, N. Y., a corporation of New Jersey.

This patent covers a specialized jig for use in assembling freight car underframes.

2,553,970—Welding Apparatus—Stanley M. Humphrey, Warren, Ohio, assignor to The Taylor-Winfield Corp., Warren, Ohio, a corporation of Ohio.

Humphrey's patent covers welding apparatus including a capacitor for storing welding energy, an a.-c. source and means for charging this capacitor from the current source and including a transformer having its primary adapted to be connected to the power source and its secondary connected to the capacitor through a rectifier. An inductive welding load circuit is also provided and means connect the capacitor to this load circuit for discharge. Other operative means are provided so that upon actuation of the means for discharging the capacitor, they provide a current conductive path in shunt with the secondary. Thus during discharge of the capacitor, the rectifier and the current conductive path provide a unidirectional current-carrying path in shunt with the capacitor.

2,554,233—Brazing Alloys—Richard E. Ballentine, Snyder, and Robert L. Zimmer, Akron, N. Y., assignors to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

This new patented brazing alloy is composed of 4.5 to 7.5% phosphorus, from 0.01 to 0.3% beryllium and the balance copper.

2,554,236—Arc-Welding Torch and Electrode—Arthur A. Bernard, Chicago, Ill.

Bernard's device relates to an electric arc-welding torch which has a head adapted to hold an electrode at a point near an exposed end thereof. This head has a cooling passage formed in part by and surrounding the electrode to carry liquid in direct contact with the electrode. Means also are present for passing liquid through this passage and carrying the liquid away from the torch.

2,554,513—Flame Cutting Apparatus—Clifford F. E. Ward, Inglewood, Calif.

This patent relates to flame-cutting apparatus which includes carrier apparatus for flexible conduits associated with flame-cutting apparatus that is mounted for reciprocation parallel to a guideway. Special flexible conduits are provided for connecting to the carrier apparatus and for aiding in the control of movement thereof.

2,555,017—Electrode Holder for Gas Blanketed Electric Arc Weldings—Roger W. Tuthill, West Springfield, Mass., assignor to General Electric Co., a corporation of New York.

This electrode holder includes a flexible nonresilient metal tubing connected at one end for receiving gas and electricity from gas and electric conduits as provided. The tubing has at least one gas outlet formed in the opposite end thereof and a silicone rubber sheath encases the tubing. Electric conducting electrode gripping means are secured to the tubing for retaining a welding electrode axially extending from within the gas outlet end of the tubing. The silicone rubber sheath constitutes a deformable protective covering and electric insulation for said metal tubing, as well as an easily detachable mounting for a gas discharge directing nozzle carried by such rubber member at the gas outlet end of the electrode holder.

2,555,481—Alternating Current Arc Welding System—Dean C. Girard, San Leandro, Calif., assignor, by mesne assignments, to National Cylinder Gas Co., a corporation of Delaware.

The patent relates to an a.-c. arc welding system wherein a transformer is provided with a primary winding connected to be variably energized from an a.-c. source and a secondary winding connected to energize a welding circuit. The welding system includes a line contactor for variably connecting the primary winding to the current source so that a relatively high or low open circuit voltage is induced in the secondary winding. A control relay is

HERE'S HOW TO
CUT ELECTRODE WASTE

Good Technique and the Right Rod for the Job Reduce Electrode Waste up to 40%

You can deposit more weld metal, in less time and avoid wasting electrodes by using approved techniques, the right electrode for the job, and by following the manufacturer's recommendations. G-E electrodes give you high deposition rates, meet AWS specifications, and are available in a wide variety of sizes and types.

Get 40 percent more from your electrodes today by:

1. **Avoiding bending whenever possible**
2. **Using electrodes down to a 2-inch stub**
3. **Providing better "fit-ups"**
4. **Protecting welding rods through better storage and care**
5. **Laying flat-face fillets on vertical fillet welds**
6. **Making fillet legs of equal length on horizontal fillets**

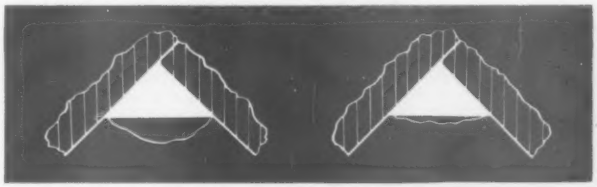
Check your horizontal and vertical fillet-welds against the illustrations on the right. Watch for future hints on improved welding techniques.

Accurate Measurement of Weldments Is Easy with this Gage

Check welds with this corrosion-resisting, stainless steel fillet-weld gage. It is a necessary tool for providing a quick, easy, accurate means of gaging fillets having either straight, concave, or convex contours of the following sizes: ¼ in., ⅜ in., 7/16 in., ½ in., ⅝ in., and ½ in. Easy to carry, it comes complete in a leather case.

Get yours today from your nearest G-E Welding Distributor. He can give you additional hints on how to get the most from your electrodes and equipment. You can find his name in the yellow pages of your telephone directory. Look for "General Electric" under "Welding Equipment."
General Electric Company, Schenectady 5, N. Y.

ON VERTICAL FILLETS



WASTE

On vertical fillets, you may be wasting as much as 40 percent of your weld metal. A poor contour, as shown above, may be due to one or more of the following conditions:

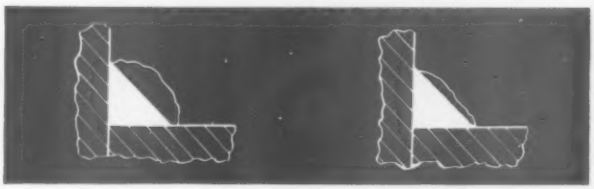
- Arc length too short
- Electrode too large
- Forward travel speed too slow
- Excess whipping
- Excessive current. Metal runs out
- Wrong electrode for the job

GOOD PRACTICE

You can prevent this needless waste of electrode by putting into practice one or more of the following suggestions:

- Use welding current recommended by the electrode manufacturer
- Use as large an electrode as plate thickness will allow, but not larger than 7/16 inch in diameter
- Increase travel speed
- Change to electrode better suited for this type of joint

ON HORIZONTAL FILLETS



WASTE

On horizontal fillets, you may be wasting as much as 30 percent of your weld metal. A poor contour may be due to one or more of the following conditions:

- Electrode held at wrong angle
- Electrode too small for size of fillet
- Excess current, metal runs down
- Arc length too short, causing overlap
- Forward travel speed too slow
- Wrong electrode for this type of joint

GOOD PRACTICE

You can prevent this needless waste of electrode by putting into practice one or more of the following suggestions:

- Hold electrode at proper angle
- Use as large an electrode as possible
- Use welding current recommended by the electrode manufacturer
- Increase travel speed
- Use proper electrode for this type of joint

712-6

GENERAL ELECTRIC

provided in a line contactor connected to be responsive to the induced voltage and be adapted to pick up on application of the relatively high open circuit voltage and to drop out only on completion of the welding circuit and to remain dropped out during the maintenance of a welding arc. A time delay device is also in the welding apparatus and is responsive to the picking up of a control relay after the welding operation ceases and to operate the line contactor a predetermined time thereafter to change the connections of the primary winding so that the welding circuit thereafter is energized with the low open circuit voltage.

2,556,685—Small Throat Portable Welder—William G. Dow, Ann Arbor, and Harold C. Early, Beaverton, Mich., assignors to General Motors Corp., Detroit, Mich., a corporation of Delaware.

This novel portable welder is of lightweight construction and it includes a heavy load transformer means having primary and secondary windings. These windings enclose magnetic core means and a secondary output loop connects to the secondary winding and includes a load. An inductive ratio reducing means is also included in the loop and includes wide flat conformed conductors. These conductors have a width-to-thickness ratio of at least five to one to reduce the inductance of the loop so that it will have a value of the order of one-third of the secondary winding inductance.

2,556,786—Method of Thermochemically Severing Tubular Metal Members—James L. Anderson, Closter, N. J., assignor to Air Reduction Co., Inc., a corporation of New York.

This method comprises the steps of heating the metal at the cutting zone to kindling temperature and directing against the outer surface of the tube oxygen jets arranged in a series around the tube in fixed relation to the tube and directed tangentially toward the tube. The jets are close enough together circumferentially so that without relative movement between the tube and the oxygen jets, a circumferentially continuous cut is produced having a depth at all points sufficient to cause substantially complete severance of the tube.

2,557,046—Method of and System for Obtaining Oriented Control Image of Weld Zone in Seam Welding Apparatus—Sidley O. Evans, Beaver Falls, Pa., assignor to The Babcock & Wilcox Tube Co., West Payfield, Pa., a corporation of Pennsylvania.

This patent relates to tube forming and welding apparatus having a stand of tube forming rolls immediately upstream from the weld zone and obstructing direct visual observation of the upstream end of the weld zone. The patent covers the provision of an optical element between the weld zone and the stand of tube forming rolls and in light receiving relation to the upstream end of the weld zone. An image of the upstream end of the weld zone is received by this element and a screen is arranged for direct visual observation by an operator of the apparatus. Other optical means are arranged to project the image from the element onto this screen.

LIST OF NEW MEMBERS

June 1 to June 30, 1951

ANTHONY WAYNE
Woodward, Vincent L. (B)

CHICAGO
Parson, Robert A. (B)

CLEVELAND
Howard, James W. (B)
Korenz, Steven F. (B)

COLUMBUS
Liptak, James A. (D)
Siegel, Geoffrey J. (B)

DAYTON
James, Henry A. (C)

DETROIT
Keller, Donald K. (D)
Schevo, Botvid A. (C)

HOUSTON
Wade, Newell W. (B)

LONG BEACH
Forester, Frank H. (C)

LOS ANGELES
Abbe, Charles E. (C)
Talbot, Ray L. (C)

NEW JERSEY
Gezari, Zvi (A)

NEW YORK
Archer, R. S. (B)
Stubelek, Zygmont (B)

NORTHERN NEW YORK
Vandenberg, Stuart R. (C)
Yates, George (B)

NORTHWESTERN PA.
Merz, William F. (C)

OKLAHOMA CITY
Barton, Richard S. (C)
McDaniel, John Russell (C)
Myers, Charles H. (C)

PEORIA
Rempe, Louis J. (C)
Robinson, Robert O. (C)
Roy, Robert J. (C)

PHILADELPHIA
Thomas, John (C)

PORTLAND
Oyler, L. E. (C)

ST. LOUIS
Shelton, Forest (C)

SALT LAKE CITY
Parker, Earl R. (D)
Stuart, William R. (D)

SAN FRANCISCO
Forbes, Wilson R. (C)
McCoy, Robert H. (B)

NOT IN SECTIONS
Barrington, Greig (C)
Carpenter, Samuel W. (C)
Dunn, R. A. (B)
Neuhaus, Alvin H. (B)
Nilsen, Alfred (D)
Wetzel, Richard E. (D)
Wheeler, Howard C. (D)

Members Reclassified

During the month of June

DETROIT
Sieger, G. N. (B to F)

LEHIGH VALLEY
Hill, H. O. (B to F)

MAHONING VALLEY
Oehler, Irving A. (B to A)

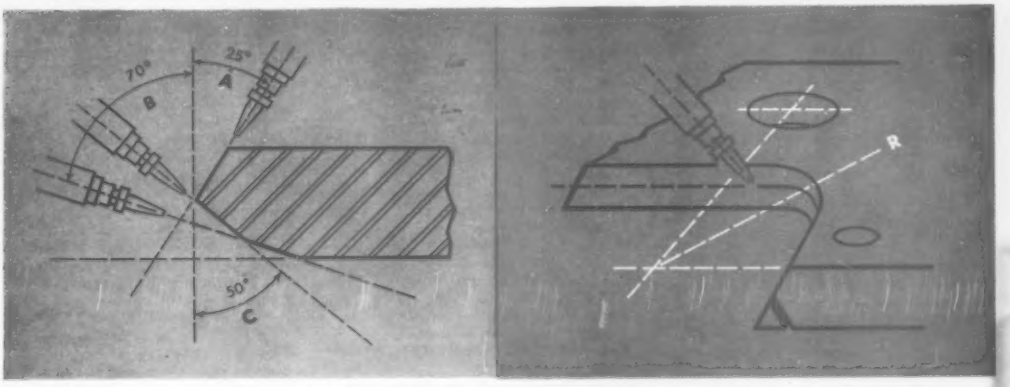
MILWAUKEE
Hansen, K. L. (B to F)

NEW YORK
Arnott, D. (B to F)
Farmer, F. M. (B to F)
Oehler, A. G. (B to F)

SYRACUSE
Malvin, Ray C. (C to B)

No more grinding edges like these on *armor plate!*

Now—the Acetogen Process allows you to *flame-cut* the most difficult bevels on armor plate *to exact tolerance*—and slash the cost of plate-edge preparation by many dollars per ton.



At last, *precision* flame-cutting of armor plate is a reality! Because of its startling accuracy, versatility, and operating characteristics, the Acetogen Process drastically slashes plate-edge preparation costs!

YOU SAVE MAN HOURS! Intricate bevels and cuts need no longer be slowly ground—they can be quickly flame-cut to ±1/16" tolerance.

YOU SAVE CAPITAL INVESTMENT! You don't need large, expensive grinding machines, or elaborate paraphernalia. The Acetogen Process utilizes standard, readily-available, low-cost equipment and tools.

YOU SAVE TRAINING TIME! Experienced flame-cutters become qualified Acetogen operators within a few days. Novices learn quicker, too, because Acetogen gas is docile, easy to use, dependable.

YOU SAVE FLOOR SPACE! You don't need a whole department devoted to grinding. The *complete* job is done in your Acetogen-cutting department.

YOU SAVE HANDLING COSTS! No need to move heavy plates from cutter to grinder; Acetogen does the job in *one* department, and with little moving of plates.

The most convincing proof of these statements comes from some of the nation's top companies—Henry Disston & Sons, Inc.; Baldwin-Lima-Hamilton Corporation; Fitzgibbons Boiler Co., Inc. These companies have continually been amazed at the speed, precision, *and economy* of the Acetogen Process.

Why not put Acetogen to work cutting *your* armor plate? We will act either as consultants, or as sub-contractors doing the entire job in your plant. *We invite your inquiry.* Acetogen Fabricators, Inc., 822 Commercial Trust Bldg., Philadelphia 2, Pa.

YOU GET THESE SPECIAL BENEFITS ONLY WITH THE ACETOGEN PROCESS

- Armor plate of all thicknesses flame-cut to ±1/16" tolerance!
- Acetogen-cut plates are ready for welding without costly grinding, finishing, bridging, or beading!
- Single- and multi-bevels are as easy to flame-cut as square-edges!
- Acetogen-cut plates have "feather" edges . . . surfaces have sufficiently low Brinell to allow machining.

ACETOGEN

FABRICATORS, INC. *Originators of precision flame-cutting*

SECTION ACTIVITIES

prepared by C. M. O'Leary

Bridgeport

The Bridgeport Section announces the election of the following officers and committee chairmen for 1951–52: *Chairman*, G. F. Mulligan, Jr., Fairfield, Conn.; *Vice-Chairman*, J. E. Creel, Peabody Engrg. Corp., Glenbrook, Conn.; *Secretary*, W. A. Seymour, Orange, Conn.; *Treasurer*, R. A. Lalli, R. A. Lalli Co., Bridgeport 6, Conn.; *Chairman, Membership Committee*, A. A. Young, Hamden, Conn.; *Chairman, Program Committee*, J. Powers, The Producto Machine Co., Bridgeport, Conn.; and *Technical Representative*, J. R. Skibo, Derby, Conn.

Chicago

The Chairman Section announces the election of the following officers and technical representative: *Chairman*, A. F. Chouinard, National Cylinder Gas Co., Chicago; *First Vice-Chairman*, I. H. Carlson, La Grange, Ill.; *Second Vice-Chairman*, Dr. John M. Parks, Armour Research Lab., Chicago; *Secretary-Treasurer*, L. C. Monroe, La Porte, Ind.; and *Technical Representative*, T. B. Jefferson, *The Welding Engineer*, Chicago.

Cleveland

Chairman John Austin called a general meeting of the 1950–51 Cleveland Section management group June 21st at Hotel Allerton. This was the kickoff meeting of a new year under "new management."

All matters concerning section activities were thoroughly discussed and a successful year assured. Particular attention was paid to program, membership maintenance and increasing the membership.

Committee reports indicated that much of the executive work on arrangements for dinner and meeting facilities had already been completed. A start was made on specific technical programs.

The top management for 1950–51, of course, are the officers and directors comprising the board of directors: John B. Austin, *Chairman;* Frank Flocke, *First Vice-President;* Jack J. Jarms, *Second Vice-Chairman;* Joe F. Wagner, *Secretary-Treasurer;* Cal Wyss, *Past-Chairman;* Ed. T. Scott, Ross Yarrow, Harold Blum and J. S. McKeighan, *Directors.*

The advisory board consists of M. S. Shane, *Chairman;* Lew Gilbert, Clayton Herrick, C. T. Elder, Robert Kriz and Frank Maine.

The committees are:

Coffee Program—Ross Yarrow, Chairman; Harold Hallstein, Vice-Chairman.

Ladies Night—Frank Maine, chairman; Nancy Flinta, Vice-Chairman.

Education and Plant Visitation—John McKeighan, chairman; T. L. Dempsey, vice-chairman.

Reception—Otto Bornemann, chairman; Ray Metzger, Jr., vice-chairman.

Nominating—Robert Kriz, chairman.

Editor—Lew Gilbert, chairman; Herbert Hinkel and Charles Berka, vice-chairman.

Tellers—Cal Wyss, chairman.

House—Ed. Scott, chairman.

Finance and Budget—Ed. Scott, chairman.

Publicity—C. T. Elder, chairman; Charles Herbruck, vice-chairman.

Advertising—Clayton Herrick, chairman.

Membership—J. Wolfenden, Jr., chairman; W. F. Stewart, vice-chairman.

Symposium—Jack Jarms, chairman; Bob Kriz, vice-chairman.

A.W.S. Publications—Wayne Durr, chairman.

Code—Bob Kriz, chairman; Harold Blum, vice-chairman.

Public Relations—Frank Maine, chairman; M. S. Shane, vice-chairman.

Program—Robert Henry, chairman.

Properties—William J. Fauser, chairman.

The Cleveland Section encourages its members to volunteer for work assignments on these committees. The committee chairman welcomes such volunteers. A.W.S. has much greater significance to those who are active in section affairs.

Dayton

The Dayton Section wound up its 1950–51 season with a picnic on the 19th of June at the Frigidaire Gun Club in Dayton, Ohio. Ninety members and guests attended, and an excellent meal with fine entertainment made the evening completely enjoyable.

The new officers for the Dayton Section were announced at this meeting as follows: *Chairman*, Clarence Shultheis, Frigidaire Div., G.M.C.; *Vice-Chairman*, Fred Schulmeister, Air Reduction; *Secretary*, Glyn Williams, Hobart Bros.; *Treasurer*, George Theriault, Frigidaire Div., G.M.C.; *Directors*, John Blankenbuehler, Robert Bowman, Howard Snyder and H. G. Weiler; *Programs*, Fred Schulmeister; *Membership Chairman*, Robert Coburn; *Technical Representative*, Al Mealey, Air Reduction Sales Co.

Detroit

On June 13th a special meeting was called by the Detroit Section Officers to discuss "Welding of Jet Engine Alloys," in response to numerous requests by representatives of Detroit automotive companies engaged in the jet engine program. The prime mover for this special meeting was Walter Garman of the General Electric Co., who procured all speakers and made all the necessary arrangements. Because of the interest in this subject, the turnout was the largest for the year with 265 people attending.

This meeting was set up as a Symposium-type meeting with each speaker allotted 15 minutes to discuss the phase of the program with which he was most familiar. When all speakers had finished with their comments, the meeting was thrown open to a general discussion period. Numerous questions were asked which demonstrated the keen interest of those attending since the discussion continued until it was necessary to close the building.

Of particular interest were the remarks made by Mr. Parks of Solar who has a considerable background of experience in this field. One fact was quite obvious, that being the lack of answers to some of the problems and the absence of applications of new processes—such as Heliarc welding and Sigma welding. This field of welding applications will undoubtedly be explored for the application of new processes to the utmost within the next year. If the attendance and interest displayed at this meeting can be used as a criterion, it certainly indicates that further meetings on this subject are in order.

In addition to Mr. Parks the speakers were M. Olchoff, Plant Equipment, Solar Aircraft; K. Koopman, Development Dept., Union Carbide Corp., and R. A. Pawley, Jet Engine Production, Dodge Division.

Houston

One hundred twenty-six members and guests had a thoroughly enjoyable time

Left to right: J. J. Dall, Vice-Chairman, S. C. Hamilton, Chairman, H. F. Crick, Secretary-Treasurer

A part of those present at the End-of-the Year Party held on June 22nd at Houston, Tex.

at the End-of-the-Year Party held at the Grand Prize Brewery on June 22nd at Houston, Tex. "Mysterious Howard" entertained with his magic, card tricks and humor, and Bill Palmer and his famous accordion played and sang favorite songs and ballads. Sixteen prizes, all the way from compacts to Glass Rod and Reel, were given away. There were three kinds of Bar-B-Que—beef, chicken and shrimp with all the trimmings. A very good time was had by all.

Officers elected for the coming season were introduced as follows: *Chairman*, S. C. Hamilton, Chicago Bridge & Iron Works; *Vice-Chairman*, J. J. Dall, Linde Air Products Co.; *Secretary-Treasurer*, H. F. Crick, Mosher Steel Co.; *Directors* (for one year, 1951–52), B. B. Drury, H. V. Mosby, Jack Stewart, James Earthman, John S. Cook and Peter J. Gurklis; (for two years, 1951–53), L. F. Megow, J. R. Pratt, H. Pape, W. C. Cox, Roy Willbern and Hal Goswell.

Indiana

The Indiana Section announces the election of the following officers for the 1951–52 season: *Chairman*, Arthur F. Wood, Indianapolis 18; *First Vice-Chairman*, Alex B. Pollock, Indianapolis 44; *Second Vice-Chairman*, Robert Evans, Western Electric Co., Indianapolis; *Secretary*, Mrs. Mercedes Spotts, P. R. Mallory & Co., Inc., Indianapolis; *Treasurer*, Paul F. Grubbs, Indianapolis; *Chairman, Membership Committee*, Robert Evans; *Chairman, Program Committee*, Alex B. Pollock; *Technical Representative*, Carl Sauer.

Mahoning Valley

The following officers have been elected by the Mahoning Valley for 1951–52: *Chairman*, O. H. Kuhlke, General American Transportation Corp., Sharon, Pa.; *First Vice-Chairman*, R. E. Heltzel, Heltzel Steel Form & Iron Co., Warren, Ohio; *Second Vice-Chairman*, H. E. Lyon, Westinghouse Electric Corp., Youngstown, Ohio; *Secretary-Treasurer*, J. H. Cordner, Westinghouse Electric Corp., Sharon, Pa.

Northern New York

The Northern New York Section announces the election of the following officers for 1951–52: *Chairman*, W. J. Van Nattan, Schenectady 9, N. Y.; *First Vice-Chairman*, S. Herres, Allegheny Ludlum Steel Corp., Watervliet, N. Y.; *Second Vice-Chairman*, C. Molenaar, General Electric Co., Schenectady, N. Y.; *Secretary-Treasurer*, I. W. Johnson, Schenectady 8, N. Y.

Northwest

The Northwest Section announces the election of the following officers for 1951–52: *Chairman*, E. L. Hixson, Minneapolis-Moline Co., Minneapolis 1; *First Vice-Chairman*, Warren F. Logemann, Brown Steel Tank Co., Minneapolis 14; *Secretary-Treasurer*, Lillian K. Polzin, Minneaplis Chamber of Commerce, Minneapolis 3; *Chairman, Membership Committee*, R. T. Schwabe, Machinery & Welder Corp., St. Paul 4; *Chairman, Program Committee*, Warren F. Logemann: *Technical Representative*, Dr. F. W. Scott, Marquette Mfg. Co., Minneapolis 14.

Northwestern Pennsylvania

The following officers and committee chairmen have been elected by the Northwestern Pennsylvania Section for 1951–52: *Chairman*, E. J. Brown, Erie, Pa.; *Vice-Chairman*, Fred T. Perry, Erie, Pa.; *Secretary-Treasurer*, W. R. Boyd, Boyd Welding Co., Erie, Pa.; *Chairman, Membership Committee*, Charles M. Richardson, The Lincoln Electric Co., Franklin, Pa.; *Chairman, Program Committee*, Fred T. Perry; *Technical Representative*, Robert K. Allen.

Pittsburgh

The Pittsburgh Section announces the election of the following officers for the 1951–52 season: *Chairman*, E. H. Turnock, Pittsburgh 21; *Vice-Chairman*, Wm. H. Kauffman, Pittsburgh 19; *Secretary-*

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ALL-STATE
All-Purpose
Cutting Electrodes

This A.C.-D.C. electrode is an important tool in the arsenal which now includes so much of American industry. *It does not require the use of oxygen.*

It is for:

1. removing welds and rivets
2. piercing and cutting armor plate, iron, cast iron, steel, stainless steel, copper, copper alloys, nickel, and nickel alloys
3. gouging and veeing
4. preparing for welding cast iron which is impregnated with grease or acid

And, it gives better results, speed and control on many metals than arc cutting with oxygen.

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WELDING ALLOYS CO. INC.
White Plains, N. Y.

Treasurer, J. F. Minnotte, Minnotte Bros. Co., Pittsburgh 7; *Chairman, Membership Committee*, A. C. Brown, Jr., Air Reduction Sales Co.; *Chairman, Program Committee*, Wm. H. Kauffman.

Puget Sound

The following officers have been elected by the Puget Sound Section for 1951–52: *Chairman*, Prof. Wm. Snyder, University of Washington, Seattle 5; *Vice Chairman*, R. C. Herman, Seattle 6; *Secretary-Treasurer*, L. R. Hayward, Air Reduction Sales Co., Seattle 4.

Richmond

The following officers have been elected by the Richmond Section for 1951–52: *Chairman*, A. A. Adcock, Old Dominion Iron & Steel Corp., Richmond, Va.; *First Vice-Chairman*, Jack Lough, Richmond, Va.; *Second Vice-Chairman*, William C. Collier, Collier Bros. Machine Works, Richmond 19; *Secretary*, W. B. Goode, W. B. Goode Co., Richmond, Va.; *Treasurer*, John G. Jones, Richmond.

Rochester

The Rochester Section announces the election of the following officers for 1951–52: *Chairman*, H. Stoler, Welding Supply Co., Rochester, N. Y.; *Vice-Chairman*, G. Stelljes, W. C. Sykes Co., Rochester 6; *Secretary-Treasurer*, W. G. Dick, Rochester 12, N. Y.; *Chairman, Membership Committee*, G. Stelljes; *Chairman, Program Committee*, C. Martin; *Technical Representative*, W. G. Dick.

Salt Lake City

The following officers have been elected by the Salt Lake City Section for 1951–52: *Chairman*, Al Bowcutt; *First Vice-Chairman*, Al Drake; *Second Vice-Chairman*, C. B. Bartlett; *Secretary*, Jack Jones, Pacific Metals Co. Ltd.; *Treasurer*, Frank Hulbert, Hulbert Bros.

Western Massachusetts

The Western Massachusetts Section announces the election of the followng officers: *Chairman*, Lee Jaeger, Jaeger Welding Supply Co., Springfield 4, Mass.; *Vice-Chairman*, Victor L. Bissonnette, Indian Orchard, Mass.; *Secretary*, Norman Randall, Springfield, Mass.; *Treasurer*, John De Marco, Springfield 5; *Chairman, Program Committee*, William Trombley; *Technical Representative*, Carl Keyser.

Wichita

The Wichita Section announces the election of the following officers for 1951–52: *Chairman*, G. M. Allend, Lampton Welding Supply Co., Wichita, Kan.: *First Vice-Chairman*, H. L. Moberly, Coleman Co., Inc., Wichita, Kan.; *Second Vice-Chairman*, D. E. Hughes, Wichita 6; *Secretary*, O. W. Daniels, Tulsa Testing Lab., Wichita 1; *Treasurer*, W. E. Bush, Wichita: *Chairman, Membership Committee*, R. L. Townsend, Tweco Products, Inc.: *Chairman, Program Committee*, H. L. Moberly.

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Effect of Prior Treatment on Precipitation of Sigma Phase

The effect of heating in the range 1700 to 2300° F. after cold deformation, and of cooling rate therefrom, on the formation of sigma phase in 18Cr – 8Ni-Cb and 25Cr – 20Ni stainless steels during subsequent exposure at 1300° F. for up to 7500 hr. is discussed and illustrated

by G. V. Smith, E. J. Dulis and H. S. Link

INTRODUCTION

With increased working temperature of modern power plants, e.g., to steam temperatures of 1050 to 1100° F., the austenitic stainless steels are being used increasingly for such applications as piping. The introduction of austenitic steel piping has brought with it a number of welding problems. Especially outstanding in this respect is that of the serviceability of welded joints between austenitic and ferritic steels. Another problem, not so widely recognized, is that of the microstructural changes, especially sigma formation, which occur during prolonged exposure at elevated temperatures, and of the effect of these on the properties.

Earlier papers from this Laboratory[1] have reviewed the literature dealing with sigma phase in stainless steels and presented results of experimental work on means of identifying this phase. The present paper describes: (1) the effect of heating at 1700, 1900, 2100 or 2300° F., followed by water-quenching, air-cooling or furnace-cooling, on the microstructure and hardness of 18Cr – 8Ni-Cb and 25Cr – 20Ni steels which previously had been cold-drawn some 40%, and (2) the effect of these treatments on precipitation of sigma when these materials are subsequently exposed (sigmatized) for up to 7500 hr. at 1300° F.

The effect on sigma formation of solution treatment temperature in the range 1700 to 2300° F., which is considerably broader than that commonly employed in commercial heat-treating practice, will be of especial interest in respect to the behavior of weld heat-affected regions. The exposure temperature of 1300° F. is somewhat higher than has as yet been employed commercially for steam pipe service (but not for other applications), and for that reason may be expected to an approximation to indicate in a relatively short time what might happen in considerably longer time at lower temperature. It would have been desirable, but was not possible, to include a number of other steels. The 18Cr – 8Ni-Cb steel has been applied to steam pipe service; to our knowledge the 25Cr – 20Ni steel has not yet been so applied, but is of interest in that it seems to be the most susceptible to sigma formation of all the common austenitic steels.

The investigation was initiated not only to determine the influence of prior treatment on the formation of sigma, but also to check the findings of Clark and Freeman[2] who had reported the occurrence of an "unknown phase" in similar steels after analogous treatments. Since the inception of our program, it has been demonstrated[3] that the unknown phase reported by Clark and Freeman was sigma, a conclusion which is corroborated by our results.

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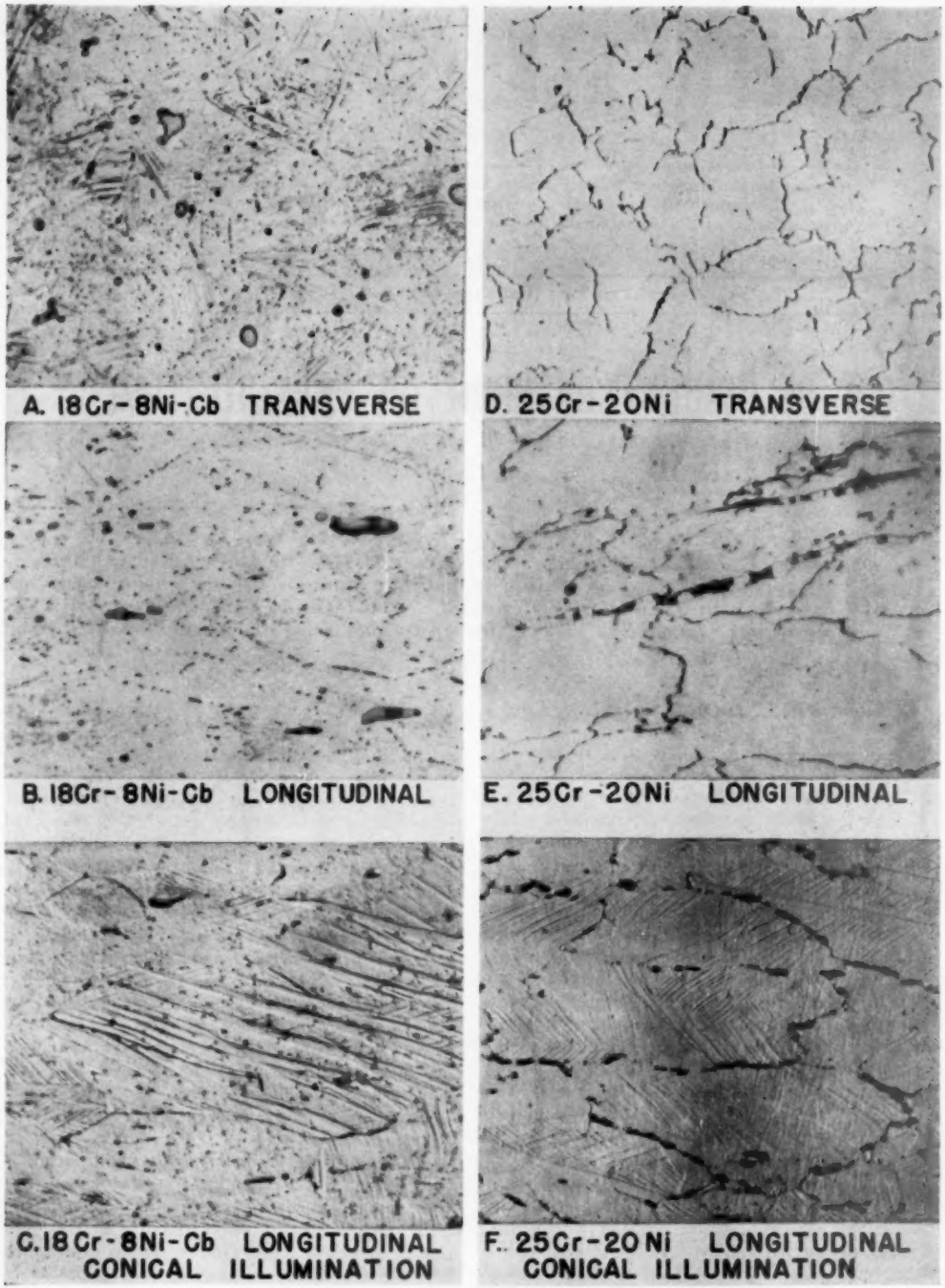


Fig. 1 Microstructure of steels as cold-worked. Etched in hydrochloric-picric acids. × *1000*

In *A*, *B*, and *C* small particles are carbides, large ones are "columbide" inclusions. Grain boundary constituent in *D*, *E* and *F* is carbide; stringers in *E* are presumably delta ferrite partially transformed to sigma. Conical illumination in *C* and *F* reveals deformation markings

Table 1

A.I.S.I. type	Nominal composition	Chemical composition, % C	Mn	P	S	Si	Cu	Ni	Cr	Cb	V
347	18Cr – 8Ni-Cb	0.07	1.21	0.014	0.018	0.43	0.02	10.80	17.10	0.89	..
310	25Cr – 20Ni	0.07	1.81	0.024	0.013	0.53	0.10	22.20	27.24	..	0.01

Degree of cold work

A.I.S.I. type	Nominal composition	Original diameter, in.	Final diameter, in.	% Reduction in area
347	18Cr – 8Ni-Cb	1.312	1.005	41.0
310	25Cr – 20Ni	1.002	0.803	36.0

MATERIALS AND PROCEDURE

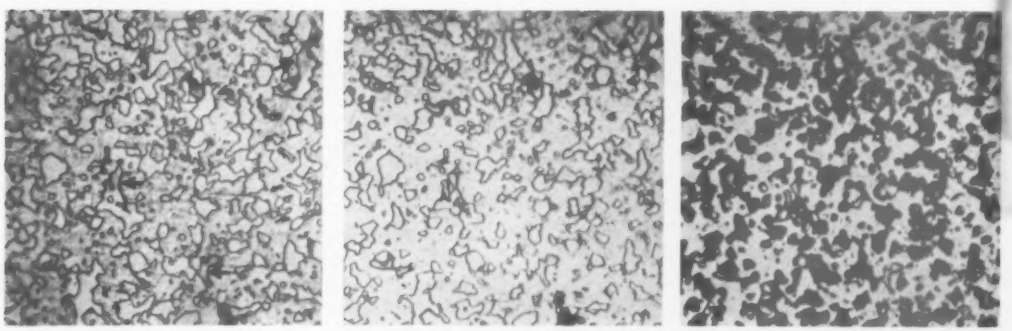
The steels were received in the form of bars; the 18Cr – 8Ni-Cb steel had been water quenched from 1975° F., whereas the 25Cr – 20Ni steel had been air-cooled after hot-forging. The bars were then cold drawn some 35 to 40% to permit the attainment of relatively fine grains by low-temperature recrystallization, since fine grains had been considered by Clark and Freeman[2] to be conducive to the formation of their "unknown phase" (sigma). The chemical composition of the steels and degree of cold work given each are listed in Table 1. It may be noted that the chromium and nickel contents of the 25Cr – 20Ni steel slightly exceed the A.I.S.I. standard limits for Type 310.

The photomicrographs of Fig. 1 illustrate the cold-drawn microstructures which are typical of cold-worked metal. The grain-boundary carbides in the 25Cr – 20Ni steel are presumably a consequence of a relatively slow rate of cooling after forging, though possibly of a relatively low forging temperature, whereas the occasional bits of what may be delta ferrite observed in this steel in the initial condition, Fig. 1 (*e*), but not in subsequently treated samples, presumably may be attributed to segregation. If ferrite, the quantity was too small to affect significantly the magnetic permeability, which was 1.0028.

Bars of each steel were heated in air for 1 hr. at 1700 1900, 2100 or 2300° F. and either water-quenched, air-cooled or furnace-cooled. A sample representative of each steel in each of these conditions was then taken, and the remainder was heated to 1300° F.; coupons were taken after 1000, 3000 and 7500 hr. at this temperature. A temperature of 1300° F. was chosen for "sigmatizing" because examination of the microstructure of specimens of another heat of 18Cr – 8Ni-Cb steel after 3000 hr. in a creep test had indicated maximum quantity of sigma at this temperature.[4]

A transverse section of each sample at a location remote from the surface was metallographically polished and examined microscopically, employing etchants suggested by a companion study.[1] The principal etchants employed were: (1) picric and hydrochloric acids in alcohol, which etched all constituents but did not permit differentiation between sigma and carbide; and (2) hydrochloric and nitric acids in glycerin (glyceregia), which did permit a differentiation between carbide and sigma in the 25Cr – 20Ni steel. In this steel sigma and carbide could also be differentiated by an electrolytic etch in chromic acid. It was not possible to differentiate with certainty between carbide and sigma in the 18Cr – 8Ni-Cb steel by etching, but the form and distribution of the two phases permitted reasonably certain identification. The presence of sigma was confirmed by x-ray diffraction, as described below.

The rather unusual etching characteristics of 25Cr – 20Ni steel containing both sigma and carbide are worthy of illustration. The photomicrographs of Fig. 2 show



(*A*) Hydrochloric-picric acids (*B*) As(A) + glyceregia (*C*) Chromic acid electrolytically

Fig. 2 Identical fields differently etched. 25Cr–20Ni steel air-cooled from 1700° F., then heated 7500 hr. at 1300° F. × 1000

Table 2—Grain Size and Hardness* of Steels

Type	Prior temperature, ° F.	Method of cooling	Austenite grain size, A.S.T.M.	Diamond pyramid hardness, 20-kg. load — Initial	After 1000 hr. at 1300° F.	After 3000 hr. at 1300° F.	After 7500 hr. at 1300°F.
347	1700	Water quenched	8	170	175	171	176
347	1700	Air-cooled	8	170	173	166	178
347	1700	Furnace-cooled	8	172	183	160	178
347	1900	Water-quenched	6–7	160	152	150	171
347	1900	Air-cooled	6–7	155	153	144	158
347	1900	Furnace-cooled	6–7	156	147	150	159
347	2100	Water-quenched	2–5	150	161	150	156
347	2100	Air-cooled	2–5	151	152	148	153
347	2100	Furnace-cooled	2–5	150	147	142	151
347	2300	Water-quenched	0–2	137	180	171	177
347	2300	Air-cooled	0–2	140	170	167	174
347	2300	Furnace-cooled	0–2	136	149	155	156
310	1700	Water-quenched	6–8	235	274	277	280
310	1700	Air-cooled	6–8	234	272	280	280
310	1700	Furnace-cooled	6–8	235	269	269	277
310	1900	Water-quenched	Mixed 2–3, 5–7	169	266	283	275
310	1900	Air-cooled	Mixed 2–3, 5–7	167	275	280	277
310	1900	Furnace-cooled	Mixed 2–3, 5–7	164	283	281	271
310	2100	Water-quenched	2–00	150	180	238	278
310	2100	Air-cooled	2–00	153	165	215	258
310	2100	Furnace-cooled	2–00	140	147	149	217
310	2300	Water-quenched	1–000	147	169	215	273
310	2300	Air-cooled	1–000	136	159	192	260
310	2300	Furnace-cooled	1–000	131	140	149	201

* Hardness of Type 347 samples after cold work, 317 DPH. Hardness of Type 310 samples after cold work, 348 DPH.

the identical field etched in three different ways. Etching with picric-hydrochloric acids in alcohol shows that a number of the massive particles, some indicated by arrows, have a two-tone appearance. This difference is not marked but is reproducible. It should be noted also that there is no "phase boundary" between the lighter and darker portions of the particles in question. On etching in glyceregia, after first etching in picric-hydrochloric acids in alcohol, however, a boundary is developed, Fig. 2 (*b*). Finally, etching electrolytically in chromic acid results in a widely different rate of attack on the two parts of the duplex particles, Fig. 2 (*c*). Comparison of the various samples, both exposed and unexposed (some of this latter group containing carbide only) after etching with different reagents led to the conclusion that the portion of the duplex particles which is not rapidly attacked during electrolytic etching in chromic acid is carbide.*

The identification of sigma under the microscope was confirmed in all cases by means of X-ray diffraction patterns. For this purpose the sigma was selectively concentrated at the surface of the sample either by long etching in picric-hydrochloric acids in alcohol (overnight, in some cases) or by electrolytic etching in ferric chloride solution. In either case the austenite matrix was preferentially attacked, leaving behind sigma and carbide standing in relief.† Chromium K-alpha radiation was employed with a recording spectrometer. By such a procedure it is possible to confirm the presence of as little as 1% sigma, as judged by microscopic examination.

Supplementing the microscopic and X-ray diffraction examinations, magnetic permeability measurements confirmed that none of the annealed or "sigmatized" samples contained ferrite. The initially cold-worked 18Cr – 8Ni-Cb steel had a permeability of 1.140 as a result of some slight transformation of austenite to ferrite during cold working. No such transformation occurred in the 25Cr – 20Ni steel, but a tiny amount (not detected magnetically) of what may be delta ferrite, or delta ferrite plus sigma, was observed in the initial microstructure as noted earlier.

Diamond pyramid hardness measurements, recorded in Table 2, were made using a 20-kg. load.

RESULTS AND DISCUSSION

25Cr – 20Ni Steel—Before Sigmatizing at 1300° F.

Sigma phase was present in relatively profuse amounts in the 25Cr – 20Ni steel after heating at 1700° F., as illustrated in Figs. 3 (*a*), (*b*) and (*c*), in which the microstructural appearance after etching with glyceregia, which reveals only the sigma phase, is compared with that after etching with picric-hydrochloric acids which shows both the sigma and carbide. Rate of cooling from 1700° F. has no apparent effect on the microstructure. It is worthy of note that although sigma is present in these samples after heating at 1700° F., Clark and Freeman[2] did not mention the occurrence of this phase (or of their unknown phase) in similar steel after similar heat treatment.

Both sigma and carbide persist in the samples heated at 1900° F., see Figs. 3 (*d*), (*e*) and (*f*), though they are

* In this respect the carbide of 25Cr – 20Ni steel differs from that in other austenitic stainless steels we have examined, wherein carbide is rapidly attacked by electrolytic chromic acid etch.

† The presence of carbide ($Cr_{23}C_6$), which yields relatively few X-ray diffraction lines, did not interfere with the identification of sigma, although the many diffraction lines of this latter phase did interfere with the identification of carbide.

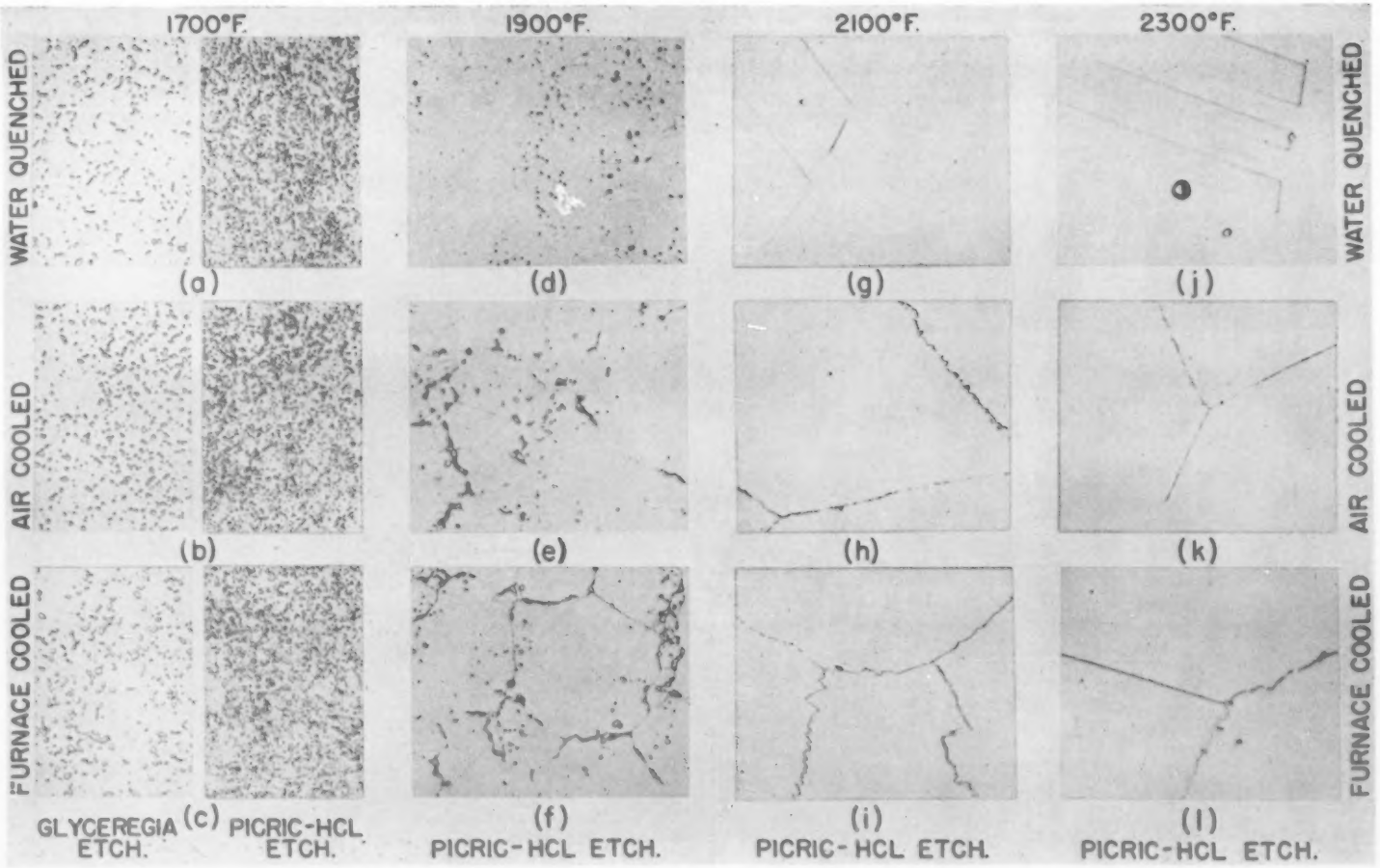


Fig. 3 Variation of microstructure of 25Cr–20Ni (Type 310) steel with temperature of prior treatment and mode of cooling therefrom. Picric-hydrochloric acids etch, except for left halves of (a), (b) and (c), which were etched in glyceregia. × 1000. (Reduced by one-third in reproduction)

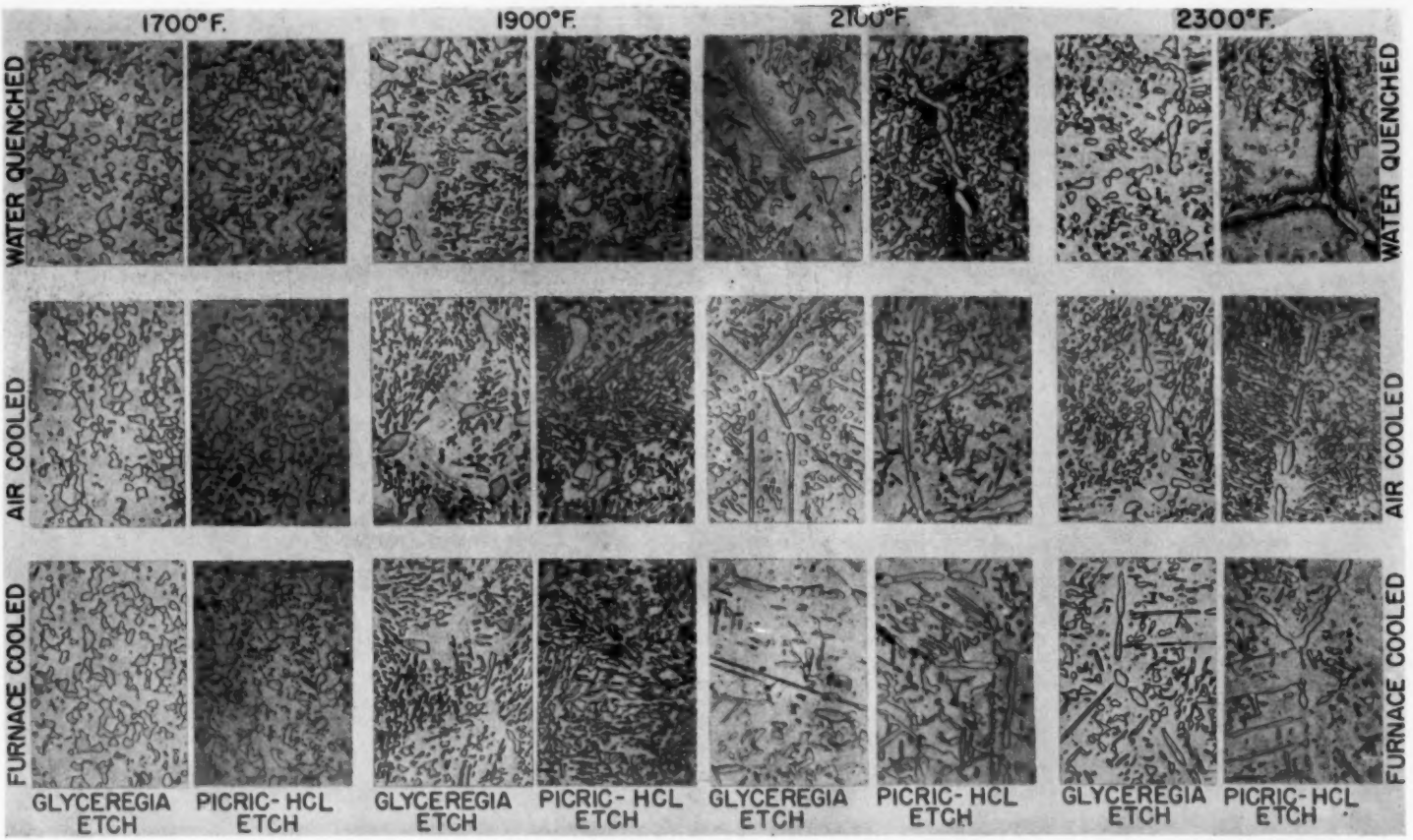


Fig. 4 Effect of temperature of prior treatment and mode of cooling therefrom on the microstructure of 25Cr–20Ni (Type 310) steel after 7500 hr. at 1300° F. Etched in glyceregia (left of each pair) or picric-hydrochloric acids (right). × 1000. (Reduced by one-third in reproduction)

not differentiated in these photomicrographs, and increase slightly in quantity with decrease of cooling rate. Since the constitution diagram[5] of the binary iron-chromium system shows the sigma phase to be stable only below about 1600° F. the occurrence of sigma in 25Cr–20Ni steel heated at 1700 and 1900° F. indicates either that nickel raises the temperature range of stability of sigma, which Bain and Griffiths[6] have shown to be true, or that insufficient time was allowed for complete solution of sigma which precipitated during heating.

This steel is free of sigma after heating at 2100 or 2300° F., and when water quenched from either temperature is also free of carbide. Slower cooling from either temperature, however, results in precipitation of carbide preferentially at the grain boundaries.

With increase of heating temperature from 1700 to 1900° F., the hardness decreased rather abruptly, Fig. 7 (*a*), and then more gradually with further increase of temperature. The relatively high hardness of the 1700° F. samples is attributable principally to the sigma phase. At the two highest temperatures the hardness was very slightly greater the faster the cooling rate; at the lower temperatures cooling rate exerted no influence.

25Cr – 20Ni Steel—After Sigmatizing at 1300° F.

On heating at 1300° F. for 7500 hr., a profuse quantity of sigma developed in this steel, amounting to a maximum of 30 to 40%. In Fig. 4, the microstructure is shown after etching in two ways: in glyceregia, which revealed the sigma phase,* and in picric-hydrochloric acids which revealed both sigma and carbide. The carbide phase appears to occur both as a relatively fine precipitate, which is surprisingly resistant to agglomeration, and as massive particles (see also Fig. 2 and associated discussion). The reason for this difference is not apparent, although a similar difference is often encountered in the spheroidization of low-alloy steels.

With reference to Fig. 4, it is apparent that the quantity and distribution of sigma phase change somewhat with the temperature of prior treatment, and for the higher temperatures, with the mode of cooling therefrom. In specimens treated at 1900° F., the sigma shows a duplex distribution with very massive particles in association with smaller particles. For prior treatment at 1700° F. the particle size is uniformly smaller, whereas for prior treatment at the two highest temperatures, the sigma shows increasingly a tendency to a Widmanstätten distribution, and especially so for sigmatizing times less than 7500 hr., not shown herein. With longer time the Widmanstätten structure agglomerates.

Although accurate measure of the quantity of sigma in various samples has not been made, visual estimation suggests that there is about the same amount of sigma, some 30 to 40%, in the 1700 and 1900° F. samples, and that this amount is independent of the cooling rate, whereas at the higher temperatures, the quantity of sigma is somewhat less and is dependent upon the cooling rate; in these instances slower cooling rates are associated with less sigma.†

The effect of rate of cooling of samples heated at 2100 or 2300° F. on precipitation of sigma at 1300° F. was even more apparent at the shorter exposure periods, the quantity being appreciably less in the more slowly cooled specimens. Sigma in these samples was initially distributed as thin Widmanstätten plates, which grew in thickness and spheroidized with longer time at 1300° F. This is reflected in the hardness results which are plotted in Figs. 7 and 8. Although the hardness of material treated at 1700 or 1900° F. attained a maximum in 1000 hr., independent of the prior cooling rate, the hardness of material treated at 2100 or 2300° F. increases more slowly, and especially so the slower the prior cooling rate. The hardness of the samples initially air-cooled from 2100 or 2300° F. has, after 7500 hr. exposure at 1300° F., just attained the maximum developed in the 1700 or 1900° F. materials, whereas that of material furnace-cooled from 2100 or 2300° F. is still increasing after 7500 hr. It is interesting to note that all samples of this steel seem to be approaching a common hardness of about 270 DPH. The magnitude of the hardness changes in this steel, attributable largely to sigma, is also noteworthy. The effect of prior furnace-cooling from a high temperature in retarding sigma formation in this steel may be of some practical value.

18Cr – 8Ni-Cb Steel—Before Sigmatizing at 1300° F.

No sigma phase was observed in any of the samples of 18Cr–8Ni-Cb steel after the different prior treatments, Fig. 5. All of the samples contain large inclusions typical of this grade of steel, which we have found by means of X-ray diffraction to have the crystal structure of CbC or CbN,* which are indistinguishable by the means at our disposal. This study will be reported separately. Samples previously treated at 1700, 1900 or 2100° F. also have fine carbides throughout the grains, no matter how cooled. These carbides were dissolved by heating to 2300° F. and were retained in solution by quenching in water; in the air-cooled, and especially in the furnace-cooled samples, however, relatively massive carbide was rejected preferentially at the grain boundaries during cooling.

As shown in Table 2, the grain size of this steel, as did that of the 25Cr–20Ni steel, increased progressively with increasing temperature.

* In most cases, the carbide also could be faintly seen in outline.

* It should be pointed out that the columbium of Type 347 steel has always contained at least a small proportion of tantalum. Although TaC has the same crystal structure and similar unit cell size as CbC and CbN, TaN is reported to have a hexagonal structure.[7]

† These conclusions were drawn from microscopic examination of the specimens, and may not be apparent in the photomicrographs of Fig. 4, owing to the limited field of view and differences between grain interior and boundary.

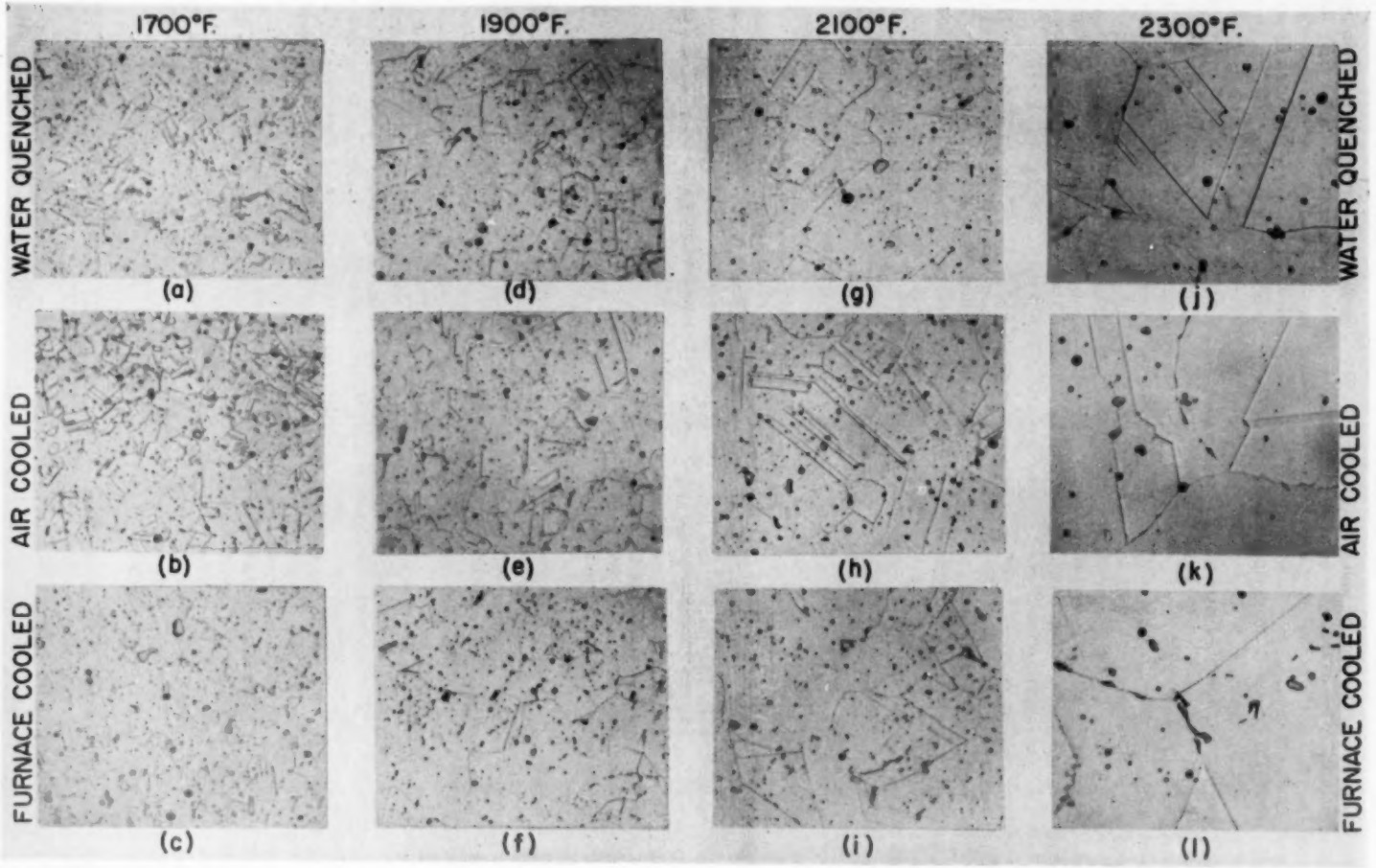


Fig. 5 Effect of temperature of prior treatment and mode of cooling therefrom on the microstructure of 18Cr–8Ni-Cb (Type 347) steel. Picric-hydrochloric acids etch. × 1000. (Reduced by one-third in reproduction)

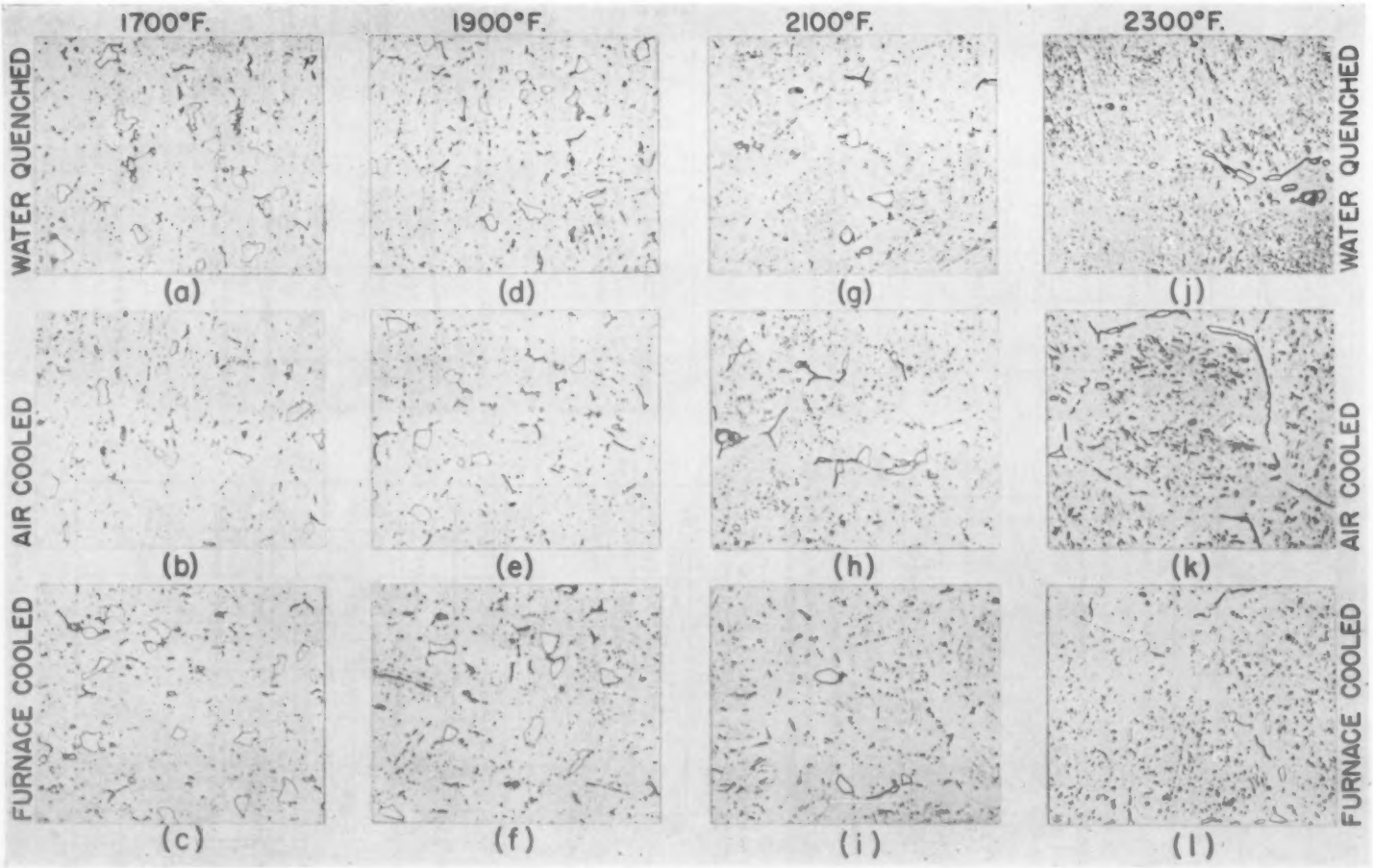


Fig. 6 Effect of temperature of prior treatment and mode of cooling therefrom on the microstructure of 18Cr–8Ni-Cb (Type 347) steel after 7500 hr. at 1300° F. Picric-hydrochloric acids etch. × 1000. (Reduced by one-third in reproduction)

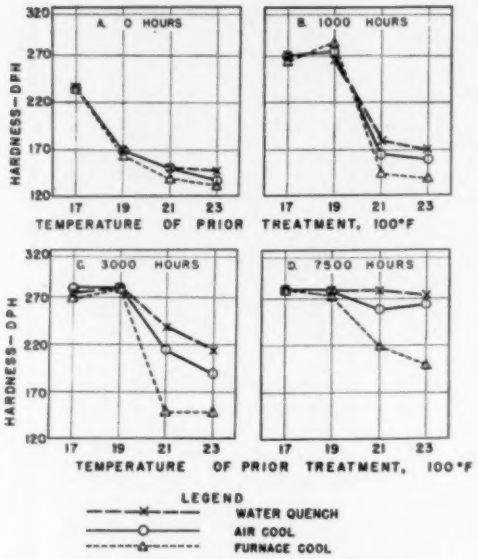


Fig. 7 Effect of prior treatment on the hardness of Type 310 (25Cr–20Ni) steel after various periods at 1300° F.

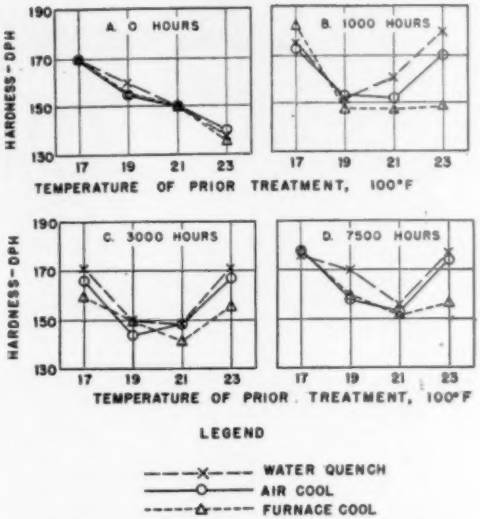


Fig. 9 Effect of prior treatment on the hardness of Type 347 (18Cr–8Ni–Cb) steel after various periods at 1300° F.

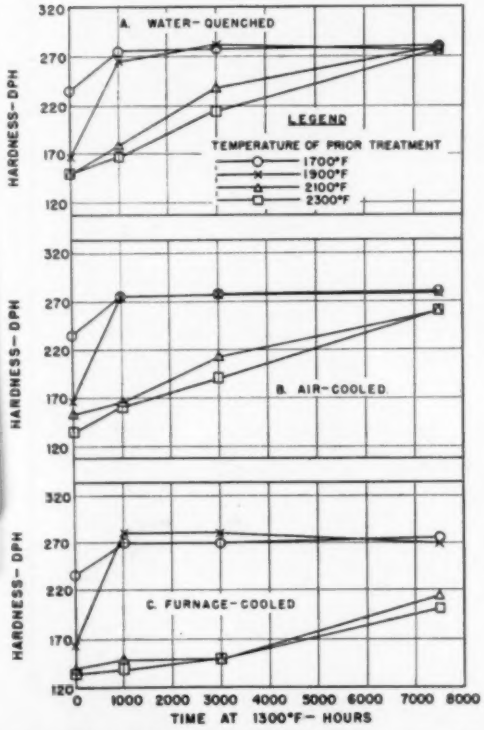


Fig. 8 Effect of time at 1300° F. on the hardness of Type 310 (25Cr–20Ni–Cb) steel following the various prior treatments

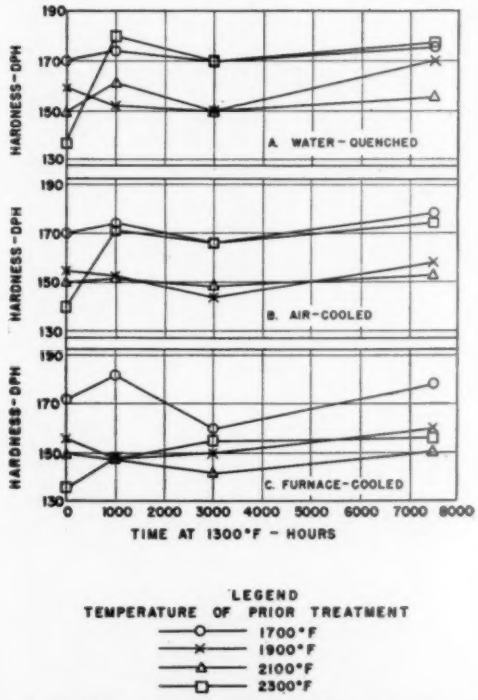


Fig. 10 Effect of time at 1300° F. on the hardness of Type 347 (18Cr–8Ni–Cb) steel following various prior treatments

The hardness of this material decreased with increase of temperature, Fig. 9 (*a*), the relation being approximately linear with no significant effect due to cooling rate.

18Cr – 8Ni-Cb Steel—After Sigmatizing at 1300° F.

All of the 18Cr–8Ni-Cb samples contained sigma after 1000 hr. or longer at 1300° F. The microstructures of the various samples after 7500 hr. are shown in Fig. 6; the hardness after this, as well as after shorter intervals, is given in Table 2 and is plotted in Figs. 9 and 10. Although X-ray diffraction provided positive proof of the presence of sigma, this phase could not be differentiated with certainty from the carbide in this steel by microscopic means, inasmuch as alkaline ferricyanide etchant (Murakami's reagent) fails to etch the carbides consistently. There can be little question, however, that the massive polyhedral particles in the photomicrographs of Fig. 6 are sigma, whereas the fine particles, as well as the thin grain boundary phase, are largely carbide. On this basis, the quantity of sigma appears to decrease somewhat with increasing temperature of prior treatment. The maximum amount of sigma is estimated to be about 8%.

The microstructure of 18Cr – 8Ni-Cb steel after 7500 hr. at 1300° F. was essentially identical for prior treatment at 1700 or 1900° F., and, as with the 25Cr – 20Ni steel, was unaffected by change of cooling rate. With further increase of the temperature of prior treatment, the sigmatized structure shows a tendency to a Widmanstätten distribution of what is believed to be largely carbide. Examination of the microstructure after the earlier exposure periods of 1000 and 3000 hr. revealed less massive sigma particles, though probably in equal amount, for both the 1700 and 1900° F. prior temperatures, whereas for the two higher temperatures, the quantity of sigma as well as the particle size increased with increasing time.

In contrast to the behavior of the 25Cr – 20Ni steel, not all of the 18Cr – 8Ni-Cb samples hardened when subjected to sigmatizing exposure, see Table 2 and Figs. 9 and 10. Only the samples treated at 2300° F. were consistently harder after exposure at 1300° F. than before. The greatest hardness is exhibited by the samples previously treated at 1700° F., and heated 1000 hr. at 1300° F. In several instances, the steel first hardens slightly and then softens with further exposure, but these slight changes may not be significant.

The hardness changes are not all clearly reflected in the observed microstructural changes, as they were in the 25Cr – 20Ni steel. This is perhaps attributable to the relatively smaller quantity of sigma which is formed. Hardness changes resulting from these small amounts of sigma may in some instances be modified significantly by the solution and rejection of carbide, change in grain size, or other factors.

GENERAL DISCUSSION

Although the quantity of sigma phase which may be developed in any one austenitic steel of the types studied herein is presumably fixed at any temperature level *when equilibrium is attained,* the actual amount occurring even after 7500 hr., and presumably for much longer, may vary within wide limits as a consequence of variations in rate of formation depending on prior treatment. Thus significant differences in microstructure may be expected across the heat-affected regions of austenitic welds. The extent to which such differences in prior treatment may influence the amount of sigma formed within fixed periods of time has been brought out strikingly by the behavior of 25Cr – 20Ni steel as herein reported.

The conditions which make possible the effects of prior treatment are presumably quite complex and difficult to analyze. Among the most important factors are probably the distribution, and perhaps composition, of the precipitated carbide (or possibly nitride) phase and the composition and associated composition gradients developed thereby in the matrix. Retention of carbide in solution by rapid cooling so that it will subsequently precipitate during the sigmatizing treatment, with a different dispersion, is another aspect of the same question. Aside from the effect of concentration differences *per se,* precipitated particles may be instrumental in nucleating sigma phase. Furthermore, from the nucleation standpoint, when, as in many of the instances shown herein, sigma nucleates preferentially at the grain boundaries, grain size may be expected to play a role independent of the concentration differences which occur in the matrix phase.

SUMMARY

The results of the investigation may be summarized as follows:

(*A*) Effect of heating in the range 1700 to 2300° F. and of rate of cooling therefrom after prior cold work:

1. Both steels completely recrystallized on heating at 1700° F. or higher.

2. The 25Cr – 20Ni steel contained a relatively large amount, perhaps 10%, of sigma after cooling from 1700° F., a very slight amount after cooling from 1900° F., but none after cooling from higher temperatures, Fig. 3. Neither the quantity nor distribution of sigma changed significantly with the cooling rate from 1700° F., but for the 1900° F. level, slower cooling yielded slightly more sigma. No sigma was observed in the 18Cr – 8Ni-Cb steel after heating at 1700 to 2300° F., Fig. 5.

3. With increase of heating temperature from 1700 to 2300° F., the carbides in either steel dissolved to an increasing extent. These were retained in solution on quenching, but again precipitated, preferentially at the grain boundaries, on air or furnace cooling. Carbides in 25Cr – 20Ni steel completely dissolved at 2100° F.

In the 18Cr–8Ni-Cb steel, particles, found to have the crystal structure of CbC or CbN, remained undissolved at the highest temperature, whereas small "carbides" were completely dissolved at this, but not lower, temperature.

4. The grain size of each alloy became coarser and the hardness decreased as heating temperature increased (Table 2), and Figs. 7 (*a*) and 9 (*a*). Except for the 25Cr–20Ni steel heated at 2100 and 2300° F., the hardness was little affected by rate of cooling; in these two instances, hardness decreased slightly with slower cooling.

(*B*) Effect of time at 1300° F.:

1. Regardless of prior treatment, both steels developed sigma during exposure at 1300° F., Figs. 4 and 6. Carbide also precipitated to an extent dependent upon the amount retained in solution during prior treatment.

2. The maximum amount of sigma observed in the 25Cr–20Ni steel was estimated to be 30 to 40%; considerably less was noted in the 18Cr–8Ni-Cb steel, the maximum being 5 to 10%. Correspondingly, the hardness changes were less pronounced in the latter steel and were no doubt much more influenced by carbide precipitation and agglomeration.

3. In 25Cr–20Ni steel previously heated to 1700 or 1900° F., the quantity of sigma developed at 1300° F. appears, from both microscopic and hardness examination, to have attained nearly its maximum value, some 30 to 40%, when sigmatized 1000 hr., the shortest interval studied. After prior treatment at higher temperature, sigma developed more slowly and was still increasing in amount at 7500 hr. The results suggested that if sufficient time were allowed, all samples would contain about the same quantity of sigma, as would be expected on the attainment of equilibrium.

4. Variation in cooling rate after prior treatment at 1700 or 1900° F. had little, if any, effect on precipitation of sigma at 1300° F. in 25Cr–20Ni steel, but after prior treatment at 2100 or 2300° F., the amount of sigma for any time at 1300° F. decreased directly with decrease of the cooling rate. This difference was especially marked during the early stages of sigmatizing.

5. In 18Cr–8Ni-Cb steel, the rate of precipitation of sigma at 1300° F. was somewhat slower for prior heat treatment at the two highest temperatures 2100 and 2300° F. than for treatment at 1700 and 1900° F., Fig. 6, but differences attributable to cooling rates were minor.

ACKNOWLEDGMENTS

We wish to acknowledge the help of R. F. Miller and J. J. Heger of United States Steel Co. and of P. L. Daley of National Tube Co. in the procurement of the test materials. P. R. Malenock assisted in the photomicrography.

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Research Projects

More than 5200 engineering research projects, representing annual expenditures of over $50.5 million, are now active in the engineering schools of American colleges and universities.

These figures highlight the 1951 edition of the "Review of Current Research," published this week by the Engineering College Research Council of the American Society for Engineering Education.

The new book, which outlines the policies and activities of engineering research in the 91 colleges and universities holding membership in E.C.R.C., is the only complete guide to the current research contributions of engineering schools, according to Dr. Gerald A. Rosselot, chairman of the Research Council and director of the State Engineering Experiment Station at the Georgia Institute of Technology.

In addition to complete research project titles, the volume shows for each school the names of responsible research administrative officers, a brief digest of policies which govern research projects and contracts at each institution, the number of personnel engaged in research activities, the annual expenditures and special conferences and short courses of interest to research workers.

The research projects listed, according to Dr. Rosselot, represent the work of more than 11,500 faculty, graduate students and research engineers.

"The obvious result of these strong programs," Dr. Rosselot said in announcing the new volume, "is an ever-increasing flow of new basic information in the engineering sciences. Equally important, however," he emphasized, "is the contribution of this research in fulfilling the educational responsibilities of scientific and engineering schools.

"In a time of national need, this catalog of educational research is significant evidence of scientific and technological resources, and it offers excellent assurance that we are laying the foundations for maintaining this strength in years to come."

All institutions holding membership in the Engineering College Research Council are represented in the new publication, according to Dr. Rosselot. E.C.R.C. membership is restricted to schools with accredited engineering curricula and extensive research activities in the engineering sciences; a total of 91 institutions are now active.

The new volume, the Research Council believes, should be a useful guide to the effective research activities and capacity in American engineering colleges and universities. Its listings of projects and personnel are complete as of Mar. 1, 1951. A complete index of research project subjects, including over 4000 entries, facilitates use of the 250-page book.

Copies of the publication, at $2.25 each, may be obtained from the Secretary of the Engineering College Research Council, at Room 7-204, 77 Massachusetts Ave., Cambridge 39, Mass.

Connections for Welded Continuous Portal Frames

Progress Report No. 4: Part II—"Theoretical Analysis of Straight Knees"*

Theoretical analysis for straight knees of a rigid frame structure forming the basis for comparing experimental results with theory. Stresses rotations and deflections are considered

by Lynn S. Beedle, A. A. Topractsoglou and Bruce G. Johnston

Foreword

Part I of this report appeared in the July 1951 issue of *Welding Research Supplement*. It included a presentation of test results for 15 welded corner connections of various types and a discussion of knee requirements.

Part II, presented here, contains the theoretical analysis for straight knees, forming the basis for a comparison of experimental results with theory. Stresses, rotations and deflections are considered.

Part III of this Progress Report No. 4 will appear in a later issue of THE WELDING JOURNAL and will include the discussion of test results and the conclusions.

I. ELASTIC ANALYSIS

F. BLEICH[25†] has proposed approximate methods for stress analysis and design of square knees. He assumes that for square knees: "... where the ratio of the length of the restraining arm to its depth is equal to or larger than one, the Navier theory yields sufficiently accurate results and one may determine the fiber stresses and shear stresses according to the conventional theory." By "restraining arm" is meant the arm AD, which acts to restrain the girder, Fig. 58.†

In the rolled section adjacent to the knee (at section AD) it has also been assumed that the ordinary beam theory applies for predicting stresses and deformations.

1. Stress Analysis of Straight Knees Without Diagonal Stiffeners*

(a) Identical Rolled Shapes

Consider connection type 7, shown in Fig. 59 (*a*). The stresses in the knee $ABCD$ are found by making the following assumptions:

1. The bending moment at the section AD is carried entirely by the flanges. In the knee shown, $M_r = V(L - (d/2))$ and the portion of the flange force, F, due to bending is given by

$$F = \frac{M_r}{d} = V\left(\frac{L}{d} - \frac{1}{2}\right)$$

The designation M_r will be used throughout this report to indicate the moment at the end of the rolled section and beginning of the knee, whether it be straight, curved or haunched. M_h is then used to denote the "haunch" moment or moment at the intersection of the neutral lines of the girder and column. In the above expression the remaining terms are defined by Fig. 59.

2. Shearing force, V, is taken by the web and is uniformly distributed.

3. The normal force, N, is considered. It is assumed to act at the flanges, however, as shown in Fig. 60.

4. The flange force varies linearly between D and C, with maximum at D and zero at C.

5. Stress concentrations are not considered.

6. Restraint due to bending of individual flange elements is neglected.

Fig. 59 (*c*) shows the forces acting on the knee. Taking into account the above assumptions, the forces and stresses are applied to the flange element as shown in Fig. 61 (*a*). Stresses on the web are indicated in Fig. 61 (*b*). Subscripts *o* and *i* represent "outside" and "inside" forces or stresses, respectively. Neglecting the

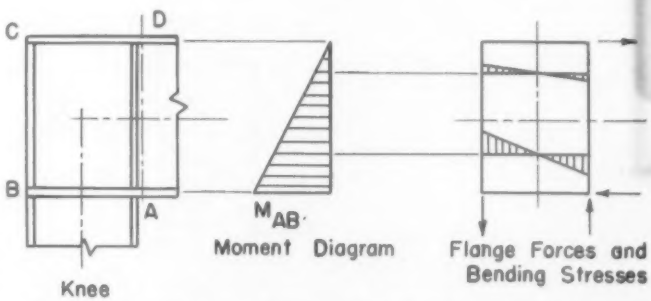

Fig. 58 Assumed moment, forces and stresses on typical straight knee

Lynn S. Beedle is Assistant to the Director, Fritz Engineering Laboratory. **A. A. Topractsoglou** is Assistant Professor of Civil Engineering with the University of Texas; formerly, Instructor at Lehigh University. **Bruce G. Johnston** was formerly Director of Fritz Engineering Laboratory, now Professor of Structural Engineering at the University of Michigan.

* This work has been carried out as a part of an investigation sponsored jointly by the Welding Research Council and the Department of the Navy with funds furnished by the following: American Institute of Steel Construction, American Iron and Steel Institute, Column Research Council (Advisory), Institute of Research, Lehigh University, Office of Naval Research (Contract No. 39303), Bureau of Ships and Bureau of Yards and Docks.

† Superior numbers indicate reference numbers listed in Part I.

* The terms "square" and "straight" are both used to designate a connection in which the girder and column rolled sections are joined at right angles without the use of additional haunch or bracket material.

† Figure numbers continue the same sequence commenced in Part I.

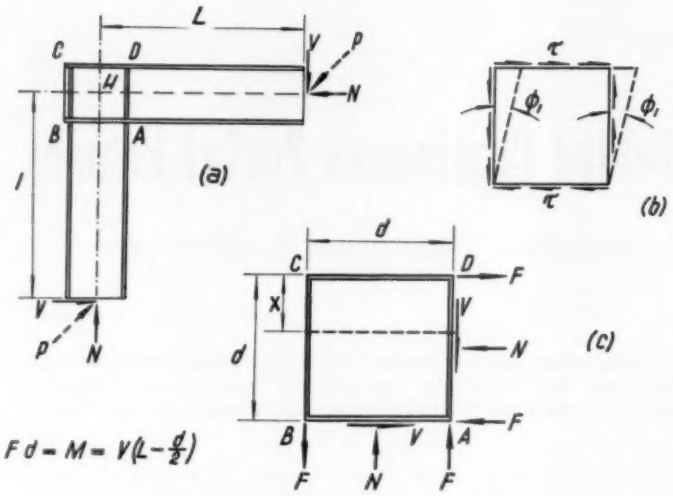

Fig. 59 Loading, forces and shear stress on Type 7 connection

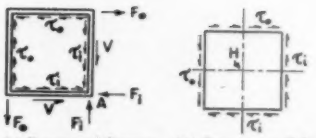

Fig. 61 Loading on flanges and on web

1. The knee web is loaded in pure shear (Fig. 61 (*b*).)

2. The stresses in the flanges forming the knee are distributed as shown in Fig. 62 (*a*), where the ordinate represents the mean normal stress in the flange cross section. Tensile stresses are plotted external to the knee.

3. To the right of section *AD*, the stresses are given by Fig. 62 (*b*).

The stress distributions shown in Fig. 63 correspond to those of Fig. 62 (*b*) except that they are computed on the basis of ordinary beam theory. Comparing the resulting stresses at section *AD* for a connection with 14WF30 members indicates a difference of about 8% which will be neglected.

The theoretical stresses may be compared to experimentally determined values on the basis of either load or moment. The latter will be used hereafter.

From the point of view of balanced de-

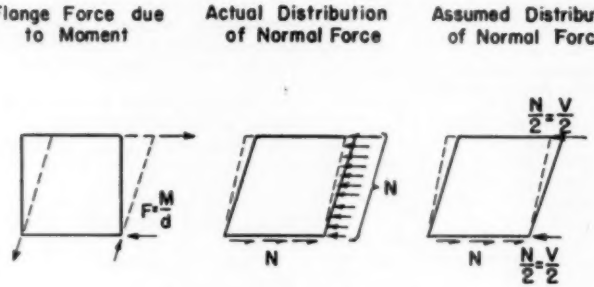

Fig. 60 Distribution of normal force

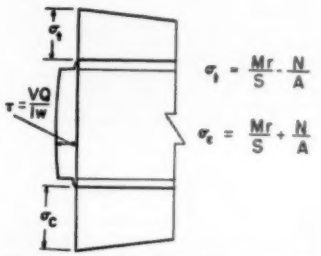

Fig. 63 Distribution of stress in girder flanges and shear stress distribution at section AD according to conventional beam theory

web and noting that $N = V$, the outside flange force is given by

$$F_o = \frac{M_r}{d} - \frac{N}{2}$$

$$F_o = \frac{V(L - d/2)}{d} - \frac{V}{2}$$

$$F_o = V\left(\frac{L}{d} - 1\right)$$

At the inside flange,

$$F_i = \frac{M_r}{d} + \frac{V}{2} = \frac{V(L - d/2)}{d} + \frac{V}{2}$$

$$F_i = \frac{VL}{d}$$

Computing the shear stresses τ on the web panel,

$$\tau_o = \frac{F_o}{A_w} = \frac{V}{A_w}\left(\frac{L}{d} - 1\right)$$

where A_w = area of the web; and

$$\tau_i = \frac{F_i - V}{A_w} = \frac{V(L/d) - V}{A_w}$$

$$\tau_i = \frac{V}{A_w}\left(\frac{L}{d} - 1\right) \qquad (1)$$

Thus

$$\tau_o = \tau_i$$

The stress distributions in the various elements are as follows:

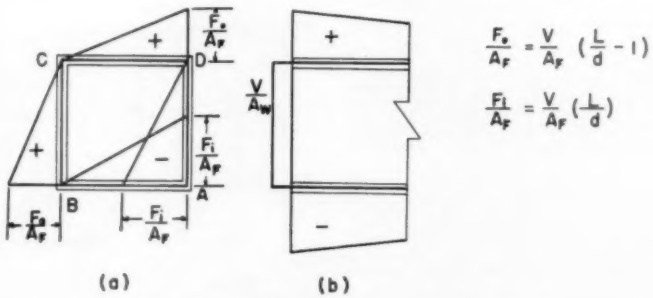

Fig. 62 Assumed stress distribution in flanges and web

sign the shear stress at point H of Fig. 61 should reach the yield value at the same external bending moment at which point A reaches the yield point in combined bending and direct stress. (Actual combined stresses will be higher elsewhere, but for engineering purposes it is considered that examination of the separate stresses at these two points is adequate.)

The stress patterns at other places in the connections were measured and a later paper will present the results as compared with the theoretically predicted values.

It is of importance that yielding due to shear force does not occur in unstiffened knee webs below the flexural yield load. Such yielding may cause large deformations. Conventional design neglects the possibility of such shear deformation and it is not practical to attempt to take it into account in routine deformation computations. Therefore, the investigation of yielding in an unstiffened knee web is desirable.

Given the square knee loaded as described previously, the problem is to find the moment under which yielding due to shear force occurs in the web.

According to the assumptions used herein, shear stresses in the knee web are uniform along horizontal sections. The actual bending stresses at section DA cause maximum shearing stresses to occur near the center of the knee web, decreasing toward the flanges. This maximum value is somewhat greater than the average uniform value, but this increase is neglected for the time being.

The following values will be substituted into Equation 1:

$$A_w = (d)(w)$$

and

$$V = \frac{M_h}{L}$$

Thus

$$\tau = \frac{M_h}{wd^2}\left(1 - \frac{d}{L}\right) \qquad (2)$$

Since the normal stresses are negligible at the center of the knee, a state of pure shear may be assumed, and

$$\sigma_1 = -\sigma_2 = \tau$$

Thus the web yields when the maximum shear stress equals

$$\tau_y = \frac{\sigma_y}{2}^*$$

in which σ_y = lower yield-point stress of web material as determined in a simple tension test. Thus from Equation 2, substituting for τ the value $\sigma_y/2$,

$$M_{h(\tau)} = \frac{\sigma_y w d^2}{2(1 - d/L)} \qquad (3)$$

where $M_{h(\tau)}$ is the moment at which yielding occurs due to shear force in the web (point H, Fig. 61 (*b*)).

* The maximum shear stress theory is conservative. More accurately by the octahedral shear stress theory, $\tau_y = 0.578\sigma_y$.

Table 1—Comparison of Yield Strengths Due to Shear and Due to Flexure for Various Rolled Shapes

Section (1)	S (2)	w (3)	d (4)	A (5)	$\frac{M_{h(\tau)}}{M_{h(\sigma)}}$ $(L/d = 6.0)$ (6)	$\frac{M_{h(\tau)}}{M_{h(\sigma)}}$ $(L = L_m)$ (7)
14WF30	41.80	0.270	13.90	8.81	0.726	0.693
8B13	9.88	0.230	8.00	3.83	0.867	0.822
21WF82	168.00	0.499	20.86	24.10	0.754	...
6B12	7.24	0.230	6.00	3.53	0.666	...
24WF110	274.40	0.510	24.16	32.36	0.633	...
8WF31	27.40	0.288	8.00	9.12	0.395	0.364

The stress at point A, Fig. 61 (*a*), is given by

$$\sigma_c = \frac{M_r}{S} + \frac{N}{A} = \frac{M_r}{S} + \frac{V}{A}$$

Since

$$M_h = VL$$

and

$$M_r = M_h(1 - (d/2L))$$

then

$$\sigma_c = M_h\left[\frac{1 - (d/2L)}{S} + \frac{1}{AL}\right]$$

$$M_{h(\sigma)} = \left[\frac{\sigma_y}{\left(\frac{1 - (d/2L)}{S}\right) + \frac{1}{AL}}\right] \qquad (4)$$

in which $M_{h(\sigma)}$ is the moment at the haunch when yielding occurs due to flexure and direct stress at the critical section DA.

If the ratio $M_{h(\tau)}/M_{h(\sigma)}$ is formed, it will be possible to determine whether a connection fabricated of a particular rolled shape will yield in the web (shear) or in the rolled shape (flexure). So long as the ratio is greater than 1.0, yielding due to shear force within the knee should not occur.

Then from Equations 3 and 4

$$\frac{M_{h(\tau)}}{M_{h(\sigma)}} = \frac{\frac{\sigma_y w d^2}{2(1 - d/L)}}{\sigma_y}\left[\frac{1 - \frac{d}{2L}}{S} + \frac{1}{AL}\right]$$

$$\frac{M_{h(\tau)}}{M_{h(\sigma)}} = \frac{wd^2}{2\left(1 - \frac{d}{L}\right)}\left[\frac{1 - \frac{d}{2L}}{S} + \frac{1}{AL}\right] \qquad (5)$$

Some commonly available rolled sections have been investigated using Equation 5 and the results are given in Table 1.

The calculation shows that "shear yielding" will usually occur prior to yielding in flexure (based on a constant L/d ratio of 6.0). An alternate basis for comparison would be obtained if the value "L_m" were selected such that Ld/bt = 600. . .a limiting case for lateral buckling. Three examples were selected and the resulting ratio is shown in Column 7. The same general trend is observed, the ratio being particularly low for the 8WF31 "column" section.

(*b*) *Stress Analysis: Dissimilar Rolled Shapes* ($d_1 \neq d_2$)

Reference is made to Fig. 64 and the assumptions stated earlier. It will be further assumed that $d_2 < d_1$. The subscripts 1 and 2 refer to members 1 and 2. Then

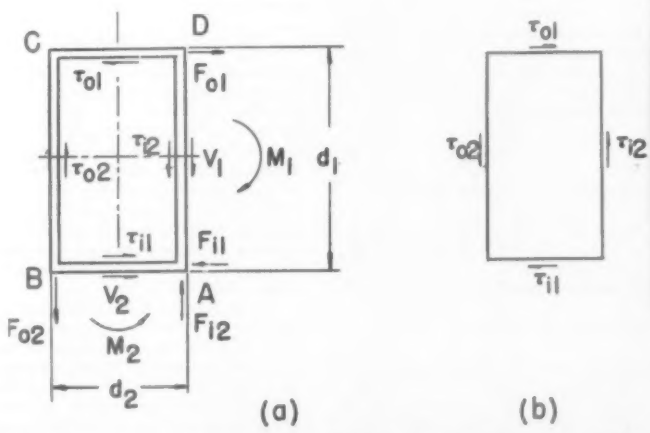

Fig. 64 Knee joining dissimilar rolled shapes; indicated are forces and shear stresses

$$F_{s1} = \frac{M_{r1}}{d_1} - \frac{V}{2}$$

$$M_{r1} = V\left(L - \frac{d_2}{2}\right)$$

$$F_{s1} = \frac{V}{d_1}\left[L - \frac{(d_1 + d_2)}{2}\right] \quad (6)$$

Also

$$F_{s1} = \frac{M_{r1}}{d_1} + \frac{V}{2}$$

$$F_{s1} = \frac{V}{d_1}\left[L + \frac{(d_1 - d_2)}{2}\right] \quad (7)$$

Similarly,

$$\left.\begin{aligned} F_{s2} &= \frac{V}{d_2}\left[L - \frac{(d_1 + d_2)}{2}\right] \\ F_{s2} &= \frac{V}{d_2}\left[L + \frac{(d_2 - d_1)}{2}\right] \end{aligned}\right\} \quad (8)$$

Since

$$\tau = \frac{F}{A_w}$$

$$\tau_{s1} = \frac{F_{s1}}{wd_2} = \frac{V}{wd_1d_2}\left[L - \frac{(d_1 + d_2)}{2}\right]$$

$$\tau_{s1} = \frac{F_{s1} - V}{wd_2} = \frac{V}{wd_1d_2}\left[L + \frac{(d_1 - d_2)}{2}\right] - \frac{V}{wd_2} = \frac{V}{wd_1d_2}\left[L - \frac{(d_1 + d_2)}{2}\right]$$

$$\tau_{s2} = \frac{F_{s2}}{wd_1} = \frac{V}{wd_1d_2}\left[L - \frac{(d_1 + d_2)}{2}\right]$$

$$\tau_{s2} = \frac{F_{s2} - V}{wd_1} = \frac{V}{wd_1d_2}\left[L + \frac{(d_2 - d_1)}{2}\right] - \frac{V}{wd_1} = \frac{V}{wd_1d_2}\left[L - \frac{(d_1 + d_2)}{2}\right]$$

All the τ's are equal and the web, neglecting small bending effects, is in a state of pure shear,

$$\tau = \frac{V}{wd_1d_2}\left[L - \frac{(d_1 + d_2)}{2}\right] \quad (9)$$

Then

$$\tau = \frac{M_k}{wd_1d_2}\left[1 - \frac{(d_1 + d_2)}{2L}\right] \quad (10)$$

An examination of initial yield in the web due to shear force and in the flange due to bending, now follows. Member "2" is smaller than member "1" and flexural yield will occur first at point A on section AB in Fig. 64. Yielding due to shear force occurs when

$$\tau = \frac{\sigma_y}{2}$$

Therefore, from Equation 10,

$$M_{k(\tau)} = \frac{wd_1d_2\sigma_y}{2}\left[\frac{1}{1 - \frac{d_1 + d_2}{2L}}\right]^* \quad (11)$$

At point A, from Equation 4,

$$\sigma_y = \frac{M_{r2}}{S_2} + \frac{V}{A_7} = \frac{M_{2r}}{S_2} + \frac{M_k}{A_2L}$$

$$\sigma_y = M_k\left[\frac{1 - d_1/2L}{S_2} + \frac{1}{A_2L}\right]$$

$$M_{k(\sigma)} = \frac{\sigma_y}{\frac{(1 - d/2L)}{S_2} + \frac{1}{A_2L}} \quad (12)$$

Applying Expressions 11 and 12 to connection test P (Type 7 knee using 8WF31 and 14WF30 shapes) and using the dimensions and properties determined from the specimens,

$$M_{k(\tau)} = 724 \text{ in.-kips.}$$
$$M_{k(\sigma)} = 1140 \text{ in.-kips.}$$

(The magnitude of $M_{k(\tau)}$ is plotted as a horizontal line in Fig. 19, Part I.)

The ratio of the two moments is

$$\frac{M_{k(\tau)}}{M_{k(\sigma)}} = \frac{724}{1140} = 0.619$$

Comparing this result with the calculations of Table 1, it is evident that the worst case is that in which the two section depths are not equal (compare 0.726 with 0.619).

Earlier in this report it was assumed that the shear stress was uniformly distributed across the web. However, according to F. Bleich's original assumption, shear stresses would be distributed in parabolic form. Thus,

$$\tau_{max.} = \frac{V_kQ_k}{I_kw_k} \quad (13)$$

where the subscripts, k, denote dimensions in the knee, Q_k is the static moment of one-half the cross section and w_k is the web thickness. Since, from Fig. 64

$$V_k = F_{s1}$$

then from equations 6, 9 and 13

$$\frac{\tau_{max.}}{\tau_{av.}} = \frac{Q_kd_2}{I_k} \quad (14)$$

Using the dimensions for test connection P,

$$\frac{\tau_{max.}}{\tau_{av.}} = 1.15$$

or the maximum shear at point H is 15% greater than the average value computed according to Equation 9. The more accurate predicted value for $M_{k(\tau)}$ is then,

$$M_{k(\tau)} = \frac{724}{1.15} = 630 \text{ in.-kips.}$$

Better agreement with the experimentally-determined value is obtained as is evident from Fig. 19, Part I. The previous expressions for "shear" yielding could all be modified by an appropriate factor Q_kd_k/I_k. However, since this would have the effect of decreasing the ratio $M_{k(\tau)}/M_{k(\sigma)}$ in Table 1, which values are already less than unity, the modification only lends further emphasis to the necessity for additional stiffening to prevent undesirable shear deformation.

The analysis presented above can at best only be considered as approximate. First of all the boundary conditions are not exactly as assumed. When the flanges are thick in proportion to the depth of the section they provide additional restraint which will enable the knee to carry more load before yielding due to shear force commences.

Secondly, residual stress is built up in the knee due to welding of the stiffeners. Presumably this alone would cause yielding to occur at a lower load than predicted.

2. *Rotation Analysis*

The knee rotation is made up of two parts: (1) Rotation due to shear, designated as γ, and (2) rotation due to bending designated as β. Since a comparison is to be made later with experimentally-determined values there is a third component to be considered: (3) Rotation due to bending of the rolled section over the length, r, between the knee and point of rotation measurement, designated as ϕ_r.

Therefore, the total knee rotation is

$$\theta = \gamma + \beta + \phi_r \quad (15)$$

(a) Type 7 Connection with Identical Members ($d_1 = d_2$)*

The assumptions of the first section will be used. From Fig. 59 (*b*) and Equation 2, the rotation due to shear is,

$$\gamma_7 = \tau/G$$

$$\gamma_7 = \frac{M_k}{wd^2G}\left(1 - \frac{d}{L}\right) \quad (16)$$

where

γ_7 = shear rotation of Type 7 connection.
G = modulus of elasticity in shear.

The rotation due to bending moment may be determined from the elongations or contractions of the flanges. As stated earlier, it is assumed that the web carries all the shear force and the flange elements carry the direct stresses.

The flange stresses were shown in Fig. 62 (*a*). Depending on the boundary conditions assumed, the flanges will deform into one of the patterns shown in Fig. 65.

In Fig. 65 (*a*), the tension flanges BC and CD elongate, but the shortening of the compression flange is not considered. In this case $\beta = 2\theta_a$. In Fig. 65 (*b*), the extension and shortening of all four flanges is considered according to the assumed stress distribution of Fig. 62; then $\beta = 2\theta_b$. In both Figs. 65 (*a*) and (*b*) point A does not shift with respect to point C since the rotation resulting from such motion is included in the shear deformation determined from Equation 16.

Since all of the extensions and contractions are small quantities, the angle θ_a will very nearly equal θ_b. It will be assumed so; because of its simplicity, the deformation pattern of Fig. 65 (*a*) will also be assumed throughout this report.

Let δ be the extension of the tension flanges BC and CD due to the average flange stress $\sigma_t/2$. Then

$$\delta = \frac{\sigma_t d}{2E}$$

and

* It is evident from this expression that the member with the thickest web should be made continuous into the knee so that the greater thickness of web will assist in carrying the shear force.

* Designation of connection types was established in Part I, Fig. 4; straight connections included in the test program are shown in Fig. 8.

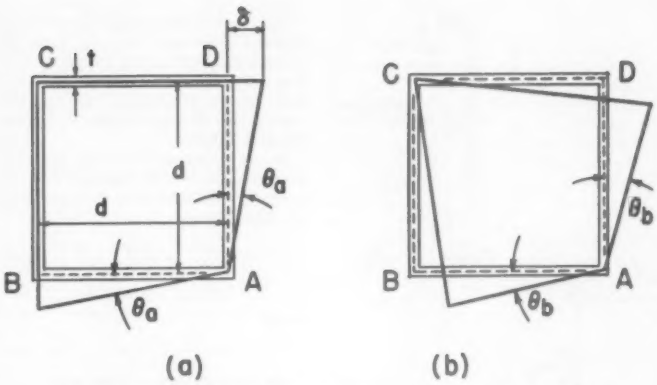

Fig. 65 Assumed knee deformations for members of equal depth

$$\theta_a = \frac{\delta}{d} = \frac{\sigma_1}{2E}$$

The total bending rotation at the knee is

$$\beta = 2\theta_a = \frac{\sigma_1}{E}$$

Neglecting the influence of direct stress,

$$\sigma_1 = \frac{(M_r)(c)}{I_F} = \frac{M_k\left(1 - \frac{d}{2L}\right)\left(\frac{d}{2}\right)}{I_F}$$

Then

$$\beta_7 = \frac{M_k\left(1 - \frac{d}{2L}\right)(d)}{2EI_F} \qquad (17)$$

where

$$I_F = 2A_F\left(\frac{d}{2} - \frac{t}{2}\right)^2$$

A_F = flange area.
t = flange thickness.

The rotation, ϕ_r, due to flexure of the rolled section over lengths r is given by

$$\phi_r = 2r\left(\frac{M_r}{EI}\right)$$

$$\phi_r = 2r\frac{M_k}{EI}\left(1 - \frac{d}{2L}\right) \qquad (18)$$

Then the total rotation from Equation 15 is given by a summation of the values determined from equations 16, 17 and 18, or

$$\theta_7 = (\gamma_7 + \beta_7 + \phi_r)$$

$$\theta_7 = \left[\frac{M_k}{wd^2G}\left(1 - \frac{d}{L}\right) + \frac{M_k}{2EI_F} \times \left(1 - \frac{d}{2L}\right)d + \frac{M_k\left(1 - \frac{d}{2L}\right)}{EI} 2r\right]$$

$$\theta_7 = M_k\left[\frac{\left(1 - \frac{d}{L}\right)}{wd^2G} + \frac{\left(1 - \frac{d}{2L}\right)d}{2EI_F} + \frac{\left(1 - \frac{d}{2L}\right)2r}{EI}\right] \qquad (19)$$

Since the test program did not include a Type 7 connection with identical members the calculation will not be carried further.

(b) Type 7 Connection with Dissimilar Members ($d_1 \neq d_2$)

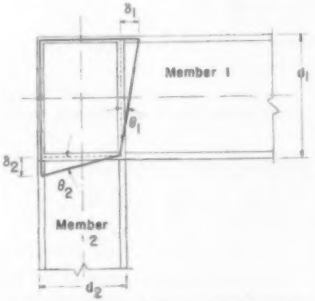

Fig. 66 Assumed knee deformations for members of unequal depth

From Equation 10,

$$\gamma_7 = \frac{\tau}{G} = \frac{M_k}{wd_1d_2G}\left[1 - \frac{(d_1 + d_2)^2}{2L}\right] \qquad (20)$$

Fig. 66 shows the flange deformations (corresponding with Fig. 65) which are the basis for computing the bending rotations. From Fig. 66

$$\beta_7 = \theta_1 + \theta_2$$

$$\theta_1 = \frac{\delta_1}{d_1} = \frac{\sigma_{f1}d_2}{2Ed_1}$$

$$\theta_2 = \frac{\delta_2}{d_2} = \frac{\sigma_{f2}d_1}{2Ed_2}$$

Since

$$\sigma_{f1} = \frac{M_k\left(1 - \frac{d_2}{2L}\right)d_1}{2I_{F1}}$$

and

$$\sigma_{f2} = \frac{M_k\left(1 - \frac{d_1}{2L}\right)d_2}{2I_{F2}}$$

then

$$\beta_7 = \frac{1}{2E}\left[\frac{d_2\sigma_{f1}}{d_1} + \frac{d_1\sigma_{f2}}{d_2}\right]$$

$$\beta_7 = \frac{M_k}{4E}\left[\frac{\left(1 - \frac{d_2}{2L}\right)d_2}{I_{F1}} + \frac{\left(1 - \frac{d_1}{2L}\right)d_1}{I_{F2}}\right] \qquad (21)$$

The rolled section rotations are computed from

$$\phi_{r1} = r_1\left[\frac{M_k}{EI_1}\left(1 - \frac{d_2}{2L}\right)\right]$$

$$\phi_{r2} = r_2\left[\frac{M_k}{EI_2}\left(1 - \frac{d_1}{2L}\right)\right]$$

Assuming the r-distances and E-values identical for the two members,

$$\phi_r = \phi_{r1} + \phi_{r2}$$

$$\phi_r = r_1\frac{M_k}{E}\left[\frac{\left(1 - \frac{d_2}{2L}\right)}{I_1} + \frac{\left(1 - \frac{d_1}{2L}\right)}{I_2}\right] \qquad (22)$$

Combining Equations 20, 21 and 22, the total rotation of a Type 7 connection with dissimilar members is given by

$$\theta_7 = (\gamma_7 + \beta_7 + \phi_r)$$

$$\theta_7 = M_k\left[\frac{1 - \frac{(d_1 + d_2)}{2L}}{wd_1d_2G} + \frac{1}{4E}\left\{\frac{\left(1 - \frac{d_2}{2L}\right)d_2}{I_{F1}} + \frac{\left(1 - \frac{d_1}{2L}\right)d_1}{I_{F2}}\right\} + \frac{r}{E}\left\{\frac{\left(1 - \frac{d_2}{2L}\right)}{I_1} + \frac{\left(1 - \frac{d_1}{2L}\right)}{I_2}\right\}\right] \qquad (23)$$

Computing the total rotation for connection P,

$$\theta_7 = (\gamma_7 + \beta_7 + \phi_r)$$

$$\theta_7 = (2.440 + 1.171 + 0.777) \times 10^{-6} M_k \text{ rad.}$$

$$\theta_7 = 4.39 \times 10^{-6} M_k \text{ rad.}$$

This theoretical moment-angle change relationship is plotted with the experimental values in Fig. 19, Part I. The relative magnitude of the components γ_7, β_7 and ϕ_r may be seen in the calculation above and it will be noted that the shear component is the largest.

(c) Connections with Diagonal Stiffeners

1. Type 2 Connections. Rotations due to shear in the square knee $ABCD$ reinforced with diagonal stiffeners (Fig. 67) will be found by making the following assumptions:

(*a*) The thrust of the two compressive forces V_aL/d is taken by the stiffeners at point A. The necessity for the designation, V_a, will be described later.

(*b*) The stress in the diagonal stiffener varies linearly from a maximum at A to zero at C. It was assumed earlier that the force, F_a, was transmitted uniformly to the web along the length CD (Fig. 67). A portion of this shear, then, is transmitted to the stiffener in proportion to the length of web intercepted by it.

(*c*) Stress concentrations are disregarded.

From assumption (*b*) it follows that the stiffener stresses cause uniform shear, τ_s, in the web of the knee. See Fig. 67 (*b*).

The moment required to deform a Type 2 connection in shear consists of two parts: (*a*) The moment necessary to shorten the

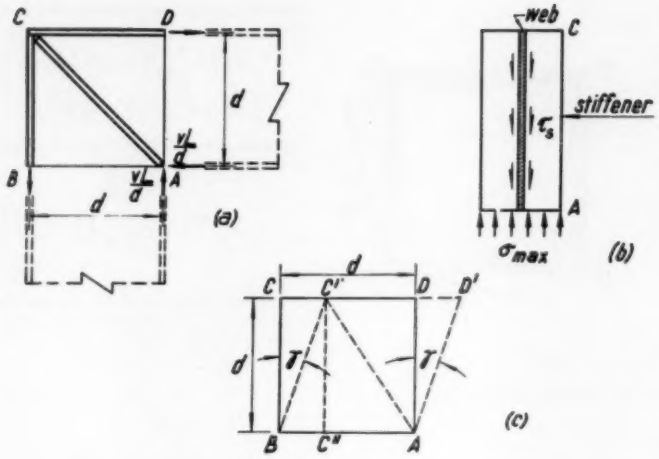

Fig. 67 Loading, forces and deformation in Type 2 connection

diagonal stiffener, and (*b*) that required to deform the web. Thus the presence of a diagonal reduces the shear stress in the web but a portion of the flange force is transmitted by the web without assistance from the diagonal stiffener.

The total contraction in the diagonal stiffener, ΔL_1, is determined from

$$\epsilon = \frac{\sigma}{E} = \frac{\Delta L_1}{\sqrt{2}d}$$

and

$$\Delta L_1 = \frac{\sigma_A}{\sqrt{2}}\frac{d}{E}$$

where

σ_A = stress at point A, Fig. 67.

$\sigma_A = \frac{\sqrt{2}F_{1a}}{A_s} = \frac{\sqrt{2}V_aL}{A_sd} = \frac{\sqrt{2}M_{ba}}{A_sd}$.

A_s = area of diagonal stiffener.

and the subscripts *a* relate to the moment associated with contraction of the stiffener. Then

$$\Delta L_1 = \frac{M_{ba}}{A_sE} \qquad (24)$$

Consider the action of the web with the stiffener removed. Due to shearing forces this web will take the shape $ABC'D'$, Fig. 67 (*c*). The following relations are then obtained:

$C'C'' = d$
$BC'' = d \sin \gamma_2 \cong d\gamma_2$
$C''A = d(1 - \gamma_2)$

where γ_2 = the shearing strain in Type 2 connections. The change in length ΔL_2 along the diagonal line AC is given by

$$\Delta L_2 = CA - C'A = d\sqrt{2} - \sqrt{d^2 + d^2(1 - \gamma_2)^2}$$

The second term may be expanded as a series, and neglecting terms of higher degree,

$$\Delta L_2 = \frac{\gamma_2 d}{\sqrt{2}} \qquad (25)$$

Since this change in length must be equal to the contraction in the stiffener, then

$$\Delta L_1 = \Delta L_2$$

and from equations 24 and 25,

$$\frac{M_{ba}}{A_sE} = \frac{\gamma_2 d}{\sqrt{2}}$$

$$M_{ba} = \frac{\gamma_2 A_s E d}{\sqrt{2}} \qquad (26)$$

In considering the second of the two moments mentioned above, it will be remembered that Equation 2 was developed for a square knee with vertical stiffener extensions of the inner beam and column flanges as sketched in Fig. 59. Such vertical stiffeners are not present in Type 2 connections. However, the web material will act somewhat in the same capacity. Assuming the same conditions as were used in developing Equation 2,

$$M_{bb} = \frac{wd^2G\gamma_2}{\left(1 - \frac{d}{L}\right)} \qquad (27)$$

Since

$$M_b = M_{ba} + M_{bb}$$

Then,

$$M_b = \gamma_2\left[\frac{wd^2}{1 - \frac{d}{L}}\,G + \frac{A_sdE}{\sqrt{2}}\right] \qquad (28)$$

from which γ_2 may be obtained.

The rotation β_2 due to bending of a Type 2 connection is determined directly from Equation 17. Similarly, the equation for rotation ϕ_r is identical with Equation 18. Thus,

$$\theta_2 = \gamma_2 + \beta_2 + \phi_r$$

as determined from expressions 17, 18 and 28. For a connection of this type joining 8B13 rolled sections (test connection *A*),

$\theta_2 = (2.50 + 4.00 + 1.45) \times 10^{-6} M_b$ rad.

$\theta_2 = 7.95 \times 10^{-6} M_b$ rad.

II. Type 8B Connections (Vertical and Diagonal Stiffeners). For the Type 8B connections with both vertical and diagonal stiffeners there appears to be less basis for an assumption regarding the transmission of flange forces, F_1, by the diagonal stiffeners.

It will be assumed, instead, that the diagonal acts as if it increased the web area and was distributed uniformly over it. From Equation 2,

$$\gamma_{2B} = \frac{\tau}{G} = \frac{1}{G}\frac{M_b}{d}\frac{\left(1 - \frac{d}{L}\right)}{A_w'} \qquad (29)$$

where

A_w' = the effective area of the web, $A_w' = A_w + A_s'$.

A_s' = equivalent stiffener area.

$A_s' = \frac{\sqrt{2}db_st_s}{d} = \sqrt{2}b_st_s$

b_s = total width of stiffener.

t_s = stiffener thickness.

The bending rotation, β_{2B}, and rolled-section rotations, ϕ_r, are computed from equations 17 and 18. Thus,

$$\theta_{2B} = (\gamma_{2B} + \beta_{2B} + \phi_r)$$

For connection *L* tested in the experimental program using an 8B13 section, from equations 17, 18 and 29,

$\theta_{2B} = (2.51 + 4.00 + 1.45) \times 10^{-6} M_b$ rad.

$\theta_{2B} = 7.96 \times 10^{-6} M_b$ rad.

This relationship is plotted in Fig. 22, Part I, as a dot-dash line.

It will be observed that this value is the same as that determined for the Type 2 connection. Although computed on the basis of different assumptions, the calculation of rotation due to shear gave practically identical results.

(*d*) *"Equivalent Length" Rotation Analysis*

In Section II, Part I, "Requirements for Connections," it was mentioned that on the basis of minimum requirements the knee should be as stiff as an equivalent length of the rolled sections joined. Several "equivalent lengths" are shown in Fig. 7 (see Part I).

As is evident from the previous derivations, the calculation of elastic deformations by the simplest methods involves many assumptions. Another point to consider is that such calculations probably are not part of a routine office procedure. Further, calculations of deformation and moment distribution are based on the implied assumption that the knee is "rigid" at the point of intersection of neutral lines but that the rest of the knee behaves as if it were part of the beam or column (Fig. 54, Part I). Thus, a calculation of the type now to be described is of importance.

1. Identical Members. It will first be

assumed that the moment is uniform along the knee length to be considered. Referring to Fig. 59a,

$$M_{AD} = M_{AB} = M_h = M_r$$

Then

$$\phi_A = \phi \Delta L$$

where

ϕ = unit rotation, M_r/EI.

Then

$$\phi_A = \frac{M_h\left(1 - \frac{d}{2L}\right)}{EI}(d + 2r) \quad (30)$$

For the 8B13 rolled shape used in the experimental investigation, for an "r" distance of 1 in.,

$$\phi_A = 7.06 \times 10^{-6} M_h \text{ rad.}$$

This relationship is plotted in Fig. 22, Part I.

II. Dissimilar Members ($d_1 \neq d_2$). Following the same procedure as in the previous section and referring to Fig. 66.

$$\phi_A = \beta_A + \phi_r$$

$$\beta_A = \frac{M_{r1}\left(\frac{d_2}{2}\right)}{EI_1} + \frac{M_{r2}\left(\frac{d_1}{2}\right)}{EI_2}$$

$$\beta_A = \frac{M_h}{2E}\left[\frac{d_2\left(1 - \frac{d_2}{2L}\right)}{I_1} + \frac{d_1\left(1 - \frac{d_1}{L2}\right)}{I_2}\right] \quad (31)$$

Evaluating β_A for connection P and adding the value ϕ_r determined from Equation 22,

$$\phi_A = 3.053 \times 10^{-6} M_h \text{ rad.}$$

This elastic relationship is plotted in Fig. 19, Part I.

The deflection relationship in the elastic range will be discussed in the next section as a part of the plastic analysis.

II. PLASTIC ANALYSIS

Yielding due to flexure alone will be discussed in this section. Thus only connections which do not yield due to shear force within the knee web will be considered. Although in the experimental program plastic deformation due to shear force occurred in one knee, it is recommended that means be taken in design to prevent such failure. It will be assumed, then, that the knee area behaves as if it were a part of the beam and column.

The basis of the plastic deformation relationships is the moment angle-change curve, often referred to as the M-ϕ curve. Methods for computing this function in the early plastic region were described by Luxion and Johnston.[6] The importance of the strain-hardening range and methods of computing the M-ϕ curve in this region have also been described and will be treated in a paper to be published in THE WELDING JOURNAL.*

In Fig. 68 the theoretical and experimental M-ϕ relationships are shown, the calculations being extended into the strain-hardening range. In these computations the results of coupon tests have been used, due account being taken for difference in material properties between the web and the flange. The upper yield point has been disregarded. The experimental curve has been obtained from the test of a simply supported beam, loaded at the third points.

By way of summary, the equations for computing some of the critical points on the complete M-ϕ curve are as follows:

1. Initial Yield

$$\left.\begin{aligned} M_1 &= \sigma_{yF} S \\ \phi_1 &= \frac{\sigma_{yF}}{E\frac{d}{2}} \end{aligned}\right\} \quad (32.1)$$

2. Yielding Penetrated to Bottom of Flange Fillet

$$\left.\begin{aligned} M_2 &= {}^2/_3\sigma_{yw}Z_2 + \sigma_{yF}(Z - Z_2) \\ \phi_2 &= \frac{\sigma_{yw}}{Ey_2} \end{aligned}\right\} \quad (32.2)$$

3. Complete Plasticity ("Plastic Hinge")

$$\left.\begin{aligned} M_3 &= \sigma_{yF}(Z - Z_3) + \sigma_{yw}Z_3 = M_p \\ \phi_3 &= \infty \text{(neglecting strain-hardening)} \\ \phi_3 &= \frac{\epsilon_s}{d/2} \text{(considering strain-hardening)} \end{aligned}\right\} \quad (32.3)$$

4. Strain-Hardening Penetrated to Bottom of Flange Fillet

$$\left.\begin{aligned} M_4 &= M_P + \frac{\sigma_4'}{\left(\frac{d}{2} - y_2\right)} \times \left[I - y_2\left(Z - \frac{Z_2}{3}\right)\right] \\ \phi_4 &= \frac{\epsilon_s}{y_2} \end{aligned}\right\} \quad (32.4)$$

5. Strain-Hardening Penetrated to a Depth Corresponding to an Extreme Fiber Stress Equal to $1.3\sigma_y$

$$\left.\begin{aligned} M_5 &= M_P + \frac{\sigma_5'}{\left(\frac{d}{2} - y_5\right)} \times \left[I - y_5\left(Z - \frac{Z_5}{3}\right)\right] \\ \phi_5 &= \frac{\epsilon_s}{y_5} \end{aligned}\right\} \quad (32.5)$$

In the above expressions,

$Z_2 = wy_2^2$

y_2 = distance from neutral axis to bottom of fillet

$\sigma_4' = \epsilon_s\left(\frac{d}{2y_2} - 1\right)C$

$\sigma_5' = 0.30\sigma_y$,

$y_5 = \frac{d}{2\left(1 + \frac{0.30\sigma_y}{C\epsilon_s}\right)}$,

$Z_5 = w(y_5)^2$.

The influence of axial load (neglected entirely in the discussion) is to cause a reduction in the moment-carrying capacity as predicted by the simple plastic theory. This has been described by Baker[20] and also in Progress Report 2.[7] As seen there,

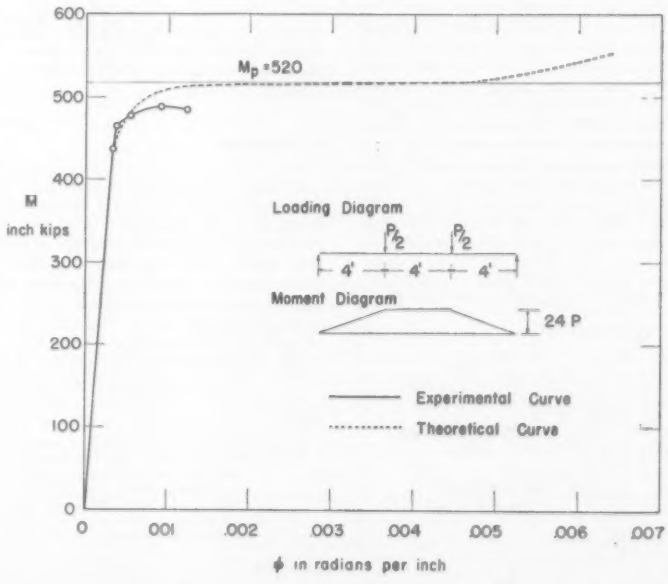

Fig. 68 Moment-curvature relationship (including strain-hardening) for 8B13 beam loaded at the third points

* Paper based on dissertation by C. H. Yang, "The Plastic Behavior of Continuous Beams," Lehigh University, 1951.

axial load does not reduce significantly the ultimate load-carrying capacity until the ratio of axial load to the buckling load exceeds about 0.10. Consequently, its influence will be neglected entirely. Such a ratio is not unusual in frames of the portal type.

1. Rotation

In an earlier part of this report, on the basis of equivalent length of the rolled section, an expression for elastic rotation was developed (Equation 30). This was derived from

$$\phi_A = \phi \Delta L$$

If it is assumed, as implied in the above expression, that the moment is uniform along the equivalent length being considered, then the M-ϕ curve (Fig. 68) in the plastic and strain-hardening ranges may be used. The unit rotations determined from Fig. 68 (Equations 32) are merely multiplied by the equivalent length ΔL. It is only necessary to correct the moment values by the ratio M_h/M_r, since the data of Fig. 68 corresponds to the moment M_r.

The results of this computation have been plotted in Fig. 22, Part I, being indicated by the dotted line. The length over which the rotation was calculated has been assumed equal to the equivalent length of connection L. According to the above assumptions, strain-hardening would not commence until the rotation reached 0.044 radians, a value not within the range of the abscissa.

According to Fig. 62 (a) it is evident that flange stresses decrease toward the outermost end of each stiffener. Thus, so far as the stiffeners are concerned, large deformations would not be expected when the beam reaches the flexural yield point.

If it were assumed that no inelastic rotation occurred within the knee, the M-ϕ_A relationship would be as shown by the dot-dash line in Fig. 69 ($\phi_A = \phi \Delta L = \phi d$). Above M_y and in the region of M_P additional inelastic rotations would merely take place in the rolled section, the M-ϕ_A relationship of which is given by the dotted

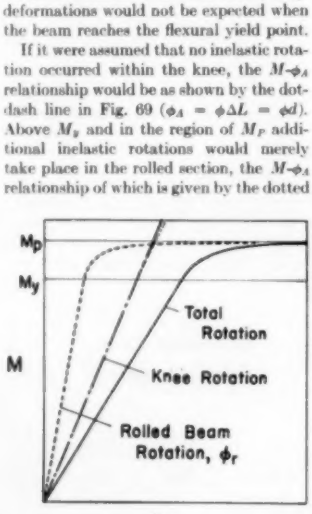

Fig. 69 Moment-curvature relationship based on equivalent length

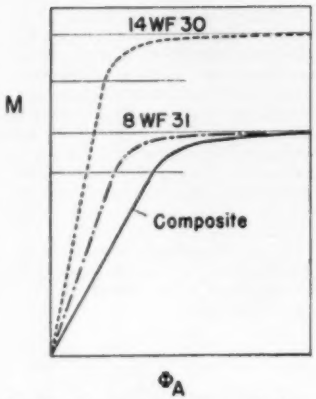

Fig. 70 Moment-curvature relationship (equivalent length) for connection with dissimilar members

curve ($\phi_A = \phi_r = \phi \times 2r$). Thus the M-ϕ_A curve of the complete connection is given by a summation of abscissas to give the solid curve.

The results of such a computation are also plotted in Fig. 22, Part I, as a dashed line.

The same summation of incremental ϕ-values could be used in case the two members were dissimilar. By this method an M-ϕ_A curve could be obtained as shown diagrammatically in Fig. 70. Using the dimensions of test connection P, similar to Fig. 66, ϕ_A for the 14WF30 shape would be computed on the basis that $\Delta L = d_2/2 + r_1$; ΔL for the second member would be $(d_1/2) + r_2$. Since yield occurred in connection P at a low load due to shear force, this flexural calculation will not be carried further in this report.

2. Deflection

A number of methods for computing deflections beyond the elastic limit have been described in the dissertation previously mentioned and are to be the subject of a later paper. Only the simplest of the methods has been used here and the resulting moment-deflection relationship is plotted in Fig. 23, Part I. The curve is computed according to the equations given below. Referring to Fig. 71,

$$\delta = \sqrt{2}\,(\delta_a + \delta_b) \qquad (33)$$

where

δ_a = deflection of the cantilever beam.
δ_b = additional deflection due to rotation of one-half of the knee computed about the intersection of the neutral lines of the members.
δ = deflection along the line of load P.

From Fig. 72,

$$\delta_a = y_1 + y_2 + y_3 \qquad (34)$$

where

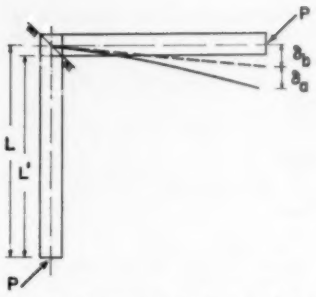

Fig. 71 Connection loading and deflection curve

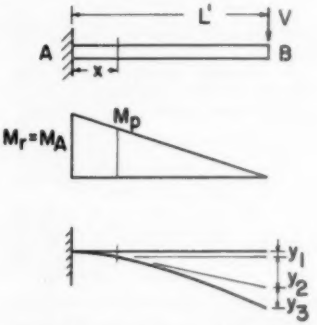

Fig. 72 Cantilever beam deflection

$$\left.\begin{aligned} y_1 &= \frac{1}{CI}\left[\frac{1}{2}M_r x^2 - \frac{M_r x^2}{3L} - \frac{BZx^2}{2}\right] \\ y_2 &= \theta_x (L' - x) \\ y_3 &= \frac{M_A}{3L'EI}(L' - x)^3 \end{aligned}\right\} (34.1)$$

I the above expressions,

$$M_r = M_h\left(1 - \frac{d}{2L}\right)$$

$$x = L'\left(1 - \frac{M_P}{M_r}\right)$$

θ_x = slope at x (Fig. 72)

$$\theta_x = \frac{1}{2CIM_r}\,[M_r^2 - M_P^2 - 2BZ(M_r - M_P)] \qquad (34.2)$$

$$L' = L - \frac{d}{2}$$

The value δ_b is given from

$$\delta_b = \frac{1}{2}\phi_A \times L \qquad (35)$$

where ϕ_A is the rotation in the knee and is determined from the modified M-ϕ curve of Fig. 73 which is the basis for this particular method. The "equivalent length" concept is used. For $0 < M_r < M_P$

$$\phi_A = \frac{M_r d}{2EI} \qquad (35.1)$$

and for $M_P < M_r < 1.3M_P$,

$$\phi_A = \left[\frac{M_r - BZ}{CI}\right]\frac{d}{2} \qquad (35.2)$$

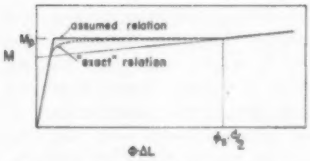

Fig. 73 Assumed and "exact" moment-curvature relationship

As is characteristic of this method for computing the load-deflection relationship the discrepancy between theory and experimental results is the greatest in the early plastic region. This lack of agreement is probably accentuated in these tests by shear deformation, a portion of which is inelastic.

NOTE: The "Discussion of Test Results" and "Summary" is to be included in Part III of this report to appear in a later issue of THE WELDING JOURNAL.

NOMENCLATURE

A = Area of cross section; A_w denotes web area, and A_r the diagonal stiffener area.

B = Intercept on the stress axis of the strain-hardening modulus line extended.

b = flange width.

C = strain-hardening modulus, $d\sigma/d\epsilon$.

d = section depth.

E = Young's modulus.

F = flange force.

f = shape factor, M_p/M_y.

G = modulus of elasticity in shear.

I = moment of inertia.

L = length of connection leg measured from load point to knee center.

L_a = length corresponding to Ld/bt = 600.

ΔL = equivalent length of connection.

M_h = moment at intersection of neutral lines of girder and column, termed "haunch" moment. Subscripts τ and σ denote moments at which yielding occurs due to shear force and flexure, respectively.

M_p = full plastic moment, often termed the "plastic hinge" moment.

M_r = connection moment at junction of rolled beam and knee.

M_y = moment at which the flexural yield-point stress is reached.

N = normal force.

Q = static moment of cross section from outer fiber to neutral axis.

r = distance from end of knee to point of rotation measurement.

S = section modulus, I/c.

t = flange thickness.

V = vertical shear force.

w = web thickness.

Z = plastic modulus; the static moment of the entire cross section about its neutral axis.

β = rotation in connection due to bending.

γ = rotation in connection due to shear.

δ = deflection.

ϵ = unit strain; subscript s denotes unit strain when strain-hardening commences.

θ = rotation.

σ = bending stress; σ_y = lower yield-point stress; subscripts F and W refer to flange and web; subscripts c and t denote compression and tension.

τ = shear stress.

ϕ = rotation per unit length.

ϕ_A = rotation determined on the basis of equivalent length.

ϕ_r = rotation (bending) in rolled section adjacent to knee.

Room Temperature Tensile Tests as an Index of Transition Temperature of Steel Plates

Discussion by W. J. Harris, Jr., J. A. Rinebolt and Richard Raring

Tör, Stout and Johnston have made an interesting analysis of the linear relationship between reduction of area in a tensile test and transition temperature measured by various notch bend and impact tests. However, in view of scatter it is necessary to question whether or not such a relationship can be applied to the prediction of transition temperature as suggested by the authors.

It has recently been shown[1] for pearlitic steels of identical composition and heat treatment that 95% of the transition temperatures (average energy definiton) determined with approximately 300 Charpy V-notch specimens fall in a band 26.8° F. wide. From reduction of area measurements, it should be possible to predict transition temperature within approximately 27° of 95% of the time, if the relationship is to be useful.

A number of data exist which can be analyzed for scatter. Figure 1, which is Fig. 6 of the paper by Tör, Stout and Johnston, shows the scatter band drawn in the original figure as well as a band drawn for purposes of this discussion to include 95% of the points. At constant reduction of area this latter band has a width of 115° F.

Since Tör, Stout and Johnston based their work on two steels in which properties were varied by deformation and subsequent heat treatment it is interesting to compare their conclusions with results of a study[2] in which transition temperature and reduction of area were varied by changes in steel composition at essentially constant microstructure. This study was made on approximately 85 steels in which 13 alloying elements were added one at a time, in increasing amounts to a base analysis. Figure 2 shows the relationship between transition temperature based on the average energy definition and reduction of area of bars pulled at room temperature, and Fig. 3 shows transition temperature based on the 15 ft.-lb. definition plotted in the same manner. The bands containing 95% of the points are approximately 185° F. wide at constant reduction

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Paper on this subject by **S. S. Tör, R. D. Stout and B. G. Johnston** was published in the September 1950 issue of the *Welding Research Supplement*.

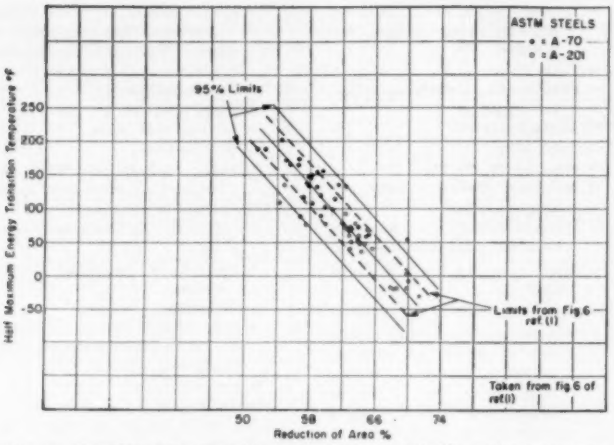

Fig. 1. Relation between reduction of area and half maximum energy transition temperature

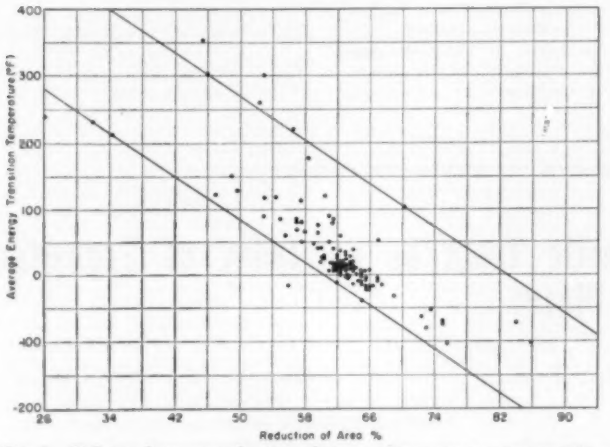

Fig. 2. Relation between reduction of area and average energy transition temperature

of area. The central rectangle of Fig. 3 includes 15 steels of nearly identical composition and heat treatment and probably represents the limits of unavoidable scatter, which amount to 25° F. in transition temperature and 5% in reduction of area.

It has been assumed thus far in this discussion that the relationship between transition temperature and reduction of area is independent of the composition of the steel. Figure 4 indicates that such an assumption is probably incorrect since carbon shifts transition temperature less rapidly for a unit change in reduction of area than manganese, phosphorus or silicon. Scatter in the relationship under discussion is probably increased by including steels of widely differing composition in the same figure.

The data of Fig. 4 can be used to explore the possibility of using reduction of area as a measure of transition temperature for steels in which only one alloying element is varied. Bands drawn to include 95% of the points of each of the 4 series of steels were found to have the scatter listed in Table 1. Even for relatively simple changes in composition, the bands are wide.

All comparisons to this point have been made at constant reduction of area. Figure 3 shows that reduction of area values for 15 very similar steels are subject to an unavoidable fluctuation of 5%. Taking this into account the scatter in the TT-RA relationship of Figs. 1, 2 and 3 is increased to the values shown in Table 2.

The suggestions were included by Tör, Stout and Johnston after study of the work of Williams and Ellinger[2] that Charpy V-notch transition temperature taken at a specified energy level might be used to determine lowest temperature of safe operation for that steel. If such a relationship ever could be established it would undoubtedly exhibit scatter which, when added to the scatter of 180 to 220° F. given in Table 2, would certainly introduce too great an uncertainty in the prediction of minimum safe operating temperature from reduction of area.

It is necessary to take these comments into account in the course of evaluating the conclusion of Mr. Boardman that "reduction in cross-sectional area during the tensile test could, if properly interpreted, be used to determine transition temperatures," since Mr. Boardman's remarks are

Table 1—Width of Scatter Bands of Transition Temperature for Series of Steels in Which One Element Is Varied

Element varied	*Width of scatter band, ° F.*
Carbon	50
Manganese	75
Phosphorus	95
Silicon	120

Table 2—Width of Scatter Bands of Transition Temperature Taking Scatter in Reduction of Area into Account

Definition of transition temperature	*Width of scatter band, ° F.*
50% max. energy (Fig. 1)	190
Average energy (Fig. 2)	225
15 ft.-lb. (Fig. 3)	240

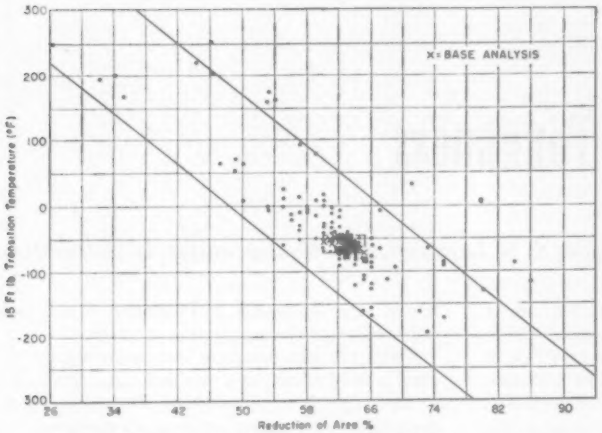

Fig. 3. Effect of reduction of area on transition temperature

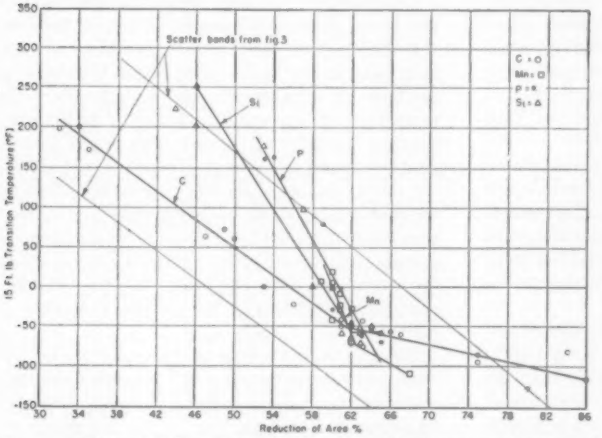

Fig. 4. Effects of C, Mn, P and Si on relationship between reduction of area and transition temperature

based on the findings of Messrs. Tör, Stout and Johnston.

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1. Rinebolt, J. A., and Harris, W. J., Jr., "Statistical Analysis of Tests of Charpy V-Notch and Keyhole Bars," THE WELDING JOURNAL, 30 (4), Research Suppl., 202-s to 208-s (1951).

2. Rinebolt, J. A., and Harris, W. J., Jr., "Effects of Alloying Elements on Notch Toughness of Pearlitic Steels," A.S.M. Preprint No. 33, 1950.

3. Williams, M. L., and Ellinger, S. A., "Investigation of Fractured Steel Plates Removed from Welded Ships," A.W.S., 1947.

Authors' Reply

The authors are grateful to Messrs. Harris, Rinebolt and Raring for their discussion.

The additional data presented by the discussers are welcome, substantiating the general relation between tensile ductility and transition temperature suggested in the paper. The authors agree fully that the usefulness of the relation is limited severely by the wide scatter of results. It is not always appreciated that a substantial portion of the scatter may originate from variations in the material itself. It may be possible to refine the method by taking into account other factors, such as composition and grain size. Multiple tensile tests can be used to reduce the scatter of ductility values.

Additional work will be required to establish the use to which this relation can be put.

Evaluating Notch Toughness

Discussion by E. M. MacCutcheon, R. H. Lambert, J. E. Walker and R. D. Schmidtman

We congratulate the authors for preparing such a comprehensive and throught-provoking paper. It is reassuring to know that the brittle fracture problem is receiving the earnest attention of the steel manufacturers and to see the subject broached in open discussion by steel metallurgists. The paper summarizes and presents in graphic form a considerable amount of data which has heretofore been available only in scattered reports. We hope that this sort of philosophical discussion and speculation can be carried on until agreement is reached regarding the factors and influences which should be considered in setting up a suitable standard for the acceptance of steel for merchant ship hull construction.

The paper by Messrs. Vanderbeck and Gensamer presents theories which are not universally accepted and which are in some respects contrary to the theories on which the research program of the Ship Structure Committee is constructed. We have pooled our ideas in the hope of suggesting other channels of thought on the subject of notch toughness.

We appreciate the problems attendant on major changes in steel manufacturing procedures but naturally look at the question of steel quality primarily from the consumers viewpoint. Acceptability standards based on service-simulated performance tests are naturally more appealing to the consumer. For this reason, it is worth while to make a further review of available data and point out areas where the consumer viewpoint leads to a contrary interpretation on a number of items covered in the paper.

Before embarking upon a discussion of the points in the paper, clarification is necessary as to the emphasis which should be placed upon the inception of a crack as against its propagation. Obviously, it is desirable to avoid the occurrence of cracks entirely, and this has been done to a large extent by improvements in design, materials and fabrication. In spite of the great strides which have been made in this direction, it is clearly unrealistic to assume that cracks will not start in ships hulls. A ship entirely devoid of incipient cracks does not appear to be a practical possibility in the foreseeable future. For this reason, it is necessary to use material which will resist the propagation of cracks.

A wide flat plate specimen is certainly not a ship, but when a sharp crack is once formed and starts to extend in the testing of such a specimen, it is reasonable to assume that the specimen will simulate the behavior of a plate in a ship which is being traversed by a crack.

Evidence from the tests shows that the fractures of the slotted plate specimens are the same as those in the ships hull. First, the thickness reductions which have been measured at the fractured edge of the slotted plate specimen for the cleavage failures are within the same range i.e., 1 to 3%, as those measured on the edges of fractures in ships hulls. Second, the appearance of the fracture surface is the same. Thickness reductions near the starting points of the fractures in the slotted plates are considerably higher as they include plastic deformation occurring before the fracture commences. This portion of the plastic deformation is not important to the comparison with shipboard failures because the conditions prevailing at the starting points are quite different.

One of the missing links in this problem is the energy required to strain the plate and propagate the fracture which occurs in a ship's hull. Recently, however we have obtained a rough idea of the magnitude of energy required to propagate the crack. Figure 1 is a

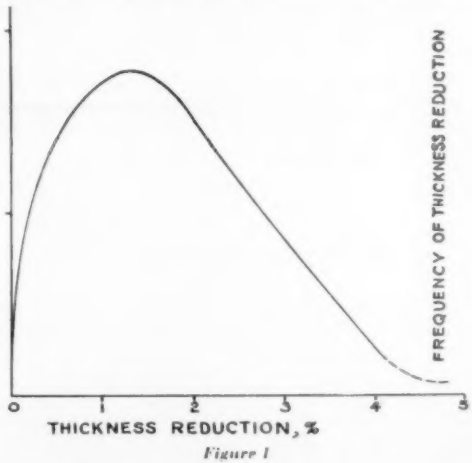

Figure 1

E. M. MacCutcheon, R. H. Lambert and **J. E. Walker** are connected with the Bureau of Ships, Dept. of Navy. **R. D. Schmidtman** is connected with the U. S. Coast Guard. Members of Ship Structure Subcommittee.

NOTE: The opinions and conclusions in this discussion are those of the authors and not necessarily those of the Navy Department, the U. S. Coast Guard nor the Ship Structure Committee.

Paper by R. W. Vanderbeck and M. Gensamer was published in the Research Supplement to the January 1950 WELDING JOURNAL, pp. 37-s to 48-s.

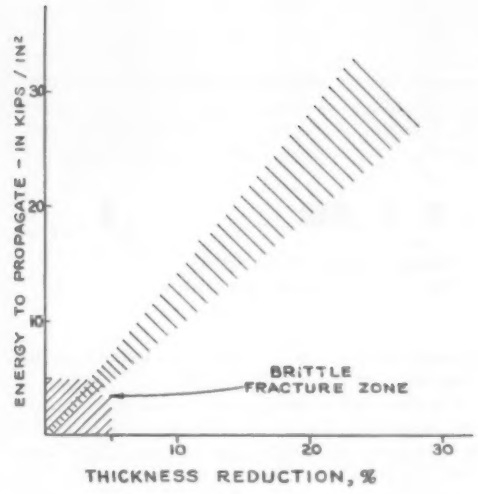

Figure 2

curve indicating the frequency with which various degrees of thickness reduction occurred at the fractured edges of plates removed from ships which had suffered casualties. These data are based upon 44 measurements made by the National Bureau of Standards and reported by Williams and Ellinger.* Figure 1 indicates that service failures involving thickness reduction of 4% have occurred. Recent studies at Swarthmore College coupled with the other test results from slotted plates show a relation between the thickness reduction at the fractured edge and the energy required to propagate the fracture in medium carbon steel. This relation is shown in Fig. 2. In the lower left-hand corner of Fig. 2 there is a shaded region called a "brittle fracture zone," based upon the possibility of having fractures involving thickness reductions as high as 4%. It will be seen that the energy absorbed may be as high as 4 in. ksi.

The authors have proposed and developed the thesis that the transition temperature as indicated by a large decrease in absorbed energy or by the change in fracture appearance on the wide centrally notched specimen, is not a true index of the behavior of the steel in a structure such as a ship. They point instead to the occurrence of a second transition at a lower temperature. They have labeled this lower transition temperature the "ductility transition."

A lower transition temperature apparently exists for certain types of tests.

* "Progress Summary on Investigation of Fractured Steel Plates Removed from Welded Ships," Morgan L. Williams and George A. Ellinger, National Bureau of Standards, Ships Structure Committee NBS-1.

This has been reaffirmed recently at the Naval Research Laboratory† by using lower tup energies in Charpy V-notch impact tests. Test results below the transition for the 12-in.-wide specimen are not numerous enough to define a second transition. In structural grades of steel the energy absorption by the 12-in.-wide specimen drops immediately to less than 10% of higher values in passing through the transition temperature range. Whether the remaining 5 or 6% energy disappears gradually or suddenly as the temperature is further reduced cannot be determined from the available data. However this appears to be inconsequential matter in so far as crack propagation is concerned.

We question the nomenclature at this point because the term "ductility transition" does not fit the circumstance very well. In many combinations of steels and test specimens it appears that the energy drop-off at the lower transition may be relatively small. If it is small for most tests which characterize crack propagation, then it is difficult to accept the name "ductility transition" for this phenomenon.

As an explanation of the occurrence of the so-called "ductility transition" the authors call attention to the occurrence of appreciable plastic strain at the root of the machined notch in slotted test specimens or other types, and to the appearance of a thumbnail pattern of shear failure. These phenomena occur at temperatures just below the "fracture" transition temperature but it should be pointed out that they do not occur in many instances. The recent series of steels at the David Taylor Model Basin* failed to reveal a thumbnail pattern in any of the 11 steels tested with the 12-in.-wide specimen. The authors leave the reader with the defi-

* "Transition Temperature of Ship Plate in Notch-Tensile Tests," E. M. MacCutcheon, C. L. Pittiglio and R. H. Raring, David Taylor Model Basin Report 709 and *Welding Research Supplement*, April 1950.

† Private communication.

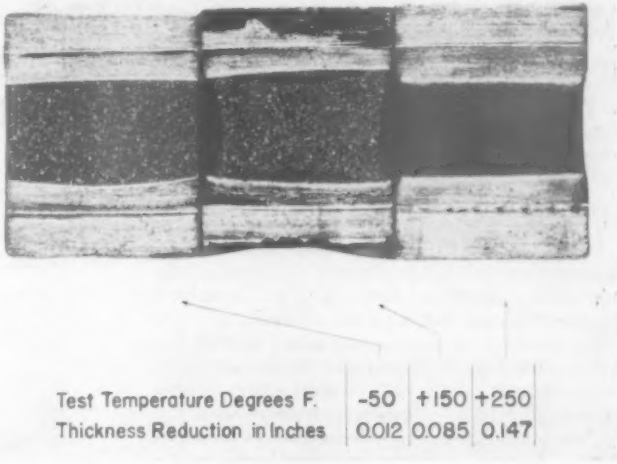

Figure 3

nite impression that there is a relation between the second transition and the thumbnail shear pattern at the edge of the notch. Evidently this is not a universal relation. Figure 3 shows the sections of three bar specimens of the tensile edge notch type tested at the David Taylor Model Basin. This steel exhibited a gradual dropping off in ductility over a wide range of temperature below the upper transition. The figure makes it clear that relation between the fracture appearance and the thickness reduction is not linear.

At some point we must stop and take stock. As engineers we must seek interim solutions. The ΔT hypothesis offers such a solution. ΔT is the arithmetic mean of the differences between transition temperatures of each steel as determined by two different methods. The relation is simple and has been established for several test methods. A dispersion of results occurs which promises the existence of a more complicated relationship. It may take years to establish the correct relationship. Meanwhile the ΔT hypothesis offers a tool for comparison because the dispersion of the relation appears acceptable within a given grade of steel. The ΔT hypothesis is assumed implicitly by Vanderbeck and Gensamer and it is the foundation of the discussion which follows.

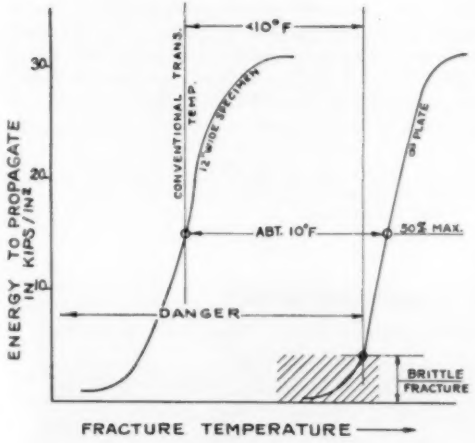

Figure 4

Figure 4 shows a hypothetical energy transition temperature curve for an infinitely wide ship plate. From tests on centrally slotted plates 12 to 72 in. in width it has been observed that the entire transition range lies within a very short zone, usually only 5 or 6° F. but seldom more than 20° F., and that the zone appears to become narrower as the plate becomes wider. A typical curve for a 12-in.-wide specimen is also shown in Fig. 4. The maximum energy level required to propagate cleavage fractures of the type observed on the ships is indicated in Fig. 4 along with a brittle fracture zone

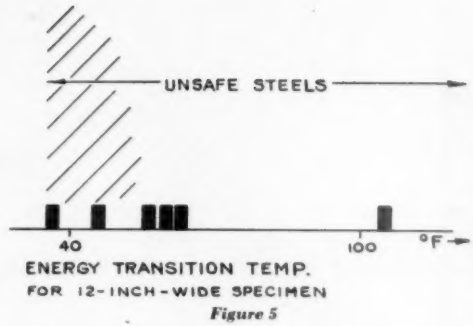

Figure 5

terminating at the point where this line crosses the transition curve for the infinite plate.

The lower limb of the curve for the 12-in.-wide plate, and presumably that of the infinitely wide plate, fall down well into the brittle fracture zone. The danger level is at 4 or 5 in. ksi., whereas the lower limbs of both curves of energy to propagate drop below 1 in. ksi. quite promptly.

The criterion which has been used generally for transition temperature in the Ship Structure Committee program has been a 50% point on the energy curve for the 12-in.-wide plate (Fig. 4) and it has been found that this point for an infinitely wide plate would lie about 10° F. or less above the point for the 12-in.-wide plate. It can be seen that the maximum value of departure between the edge of the danger zone for a wide plate and the usually reported criterion is less than 10° F. It would appear that the 50% maximum energy value is a suitable criterion for the comparison of steels and furthermore there is a good correlation between this criterion and the 50% fracture appearance criterion.

It is believed firmly that any notch test and corresponding criterion which correlates well with the data from the 12-in.-wide slotted specimen will be a suitable criterion of comparison for steels of different types within the structural range.

Having selected a suitable test, it then becomes necessary to suggest a standard for acceptance of steel. It is fairly clear that it would be desirable to eliminate steel similar to that which has fractured in shipboard service and this gives us a clue as to the range of steels which are undesirable. Figure 5 shows the transitions

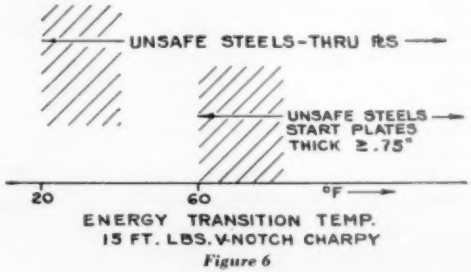

Figure 6

which were obtained in testing specimens from five fractured plates from the Tanker *Ponaganset* and one from the Liberty Ship *Pierre S. Dupont*. These plates were tested using the 12-in.-wide slotted specimen. Figure 6 is a similar chart based upon results of tests by the National Bureau of Standards in which a great number of V-notch Charpy transition curves were run.

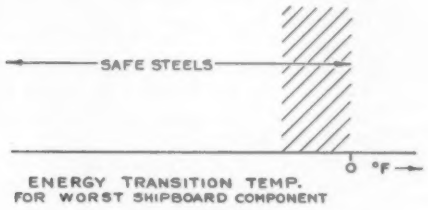

Figure 7

At the other end of the range, we may say that any steel which will not produce a brittle cleavage fracture when used in the worst shipboard component and at a temperature equal to the lowest operating condition is a safe steel. An extensive survey of ship operating conditions for the Liberty Ship indicated that the temperature of operation seldom drops below 0° F. for the upper structure and never below about 28° F. for the bottom structure. The region of safe steels is indicated in Fig. 7 where the dividing line is 0°. A severe shipboard geometry was the original Liberty Ship hatch corner. This square hatch corner involved a superpositioning of notches in three mutually perpendicular planes. In addition there was a weld system which intersected at the same point and in such a fashion that a severe cavity existed at the critical location. This geometry was the starting point of many fractures. In fact, it was so severe that it is generally conceded to be about the worst geometry that could ever be expected in a ship design. For this reason it was tested using some of the project steels which had already been tested in the 12-in.-wide slotted plate specimen. Figure 8 is a comparison for the two steels in the structural range which were tested using both the hatch type specimen and the 12-in.-wide specimen. It will be noted that for Steel B, the transition temperature difference is 30° and for Steel C, it is 50° F. The average temperature difference between the 12-in.-wide specimen and the hatch corner is 40° on the basis of Fig. 8.

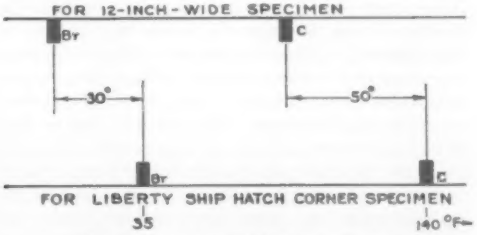

Fig. 8 Energy transition temperature

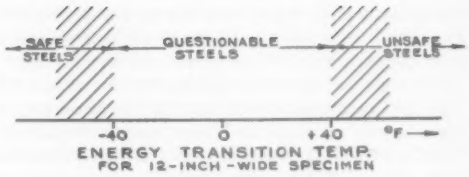

Figure 9

Tests on some dozen or so steels have indicated that a rough relation exists also between the V-notch Charpy bar and the 12-in.-wide specimen, and that the V-notch Charpy has a transition temperature of approximately 20° F. below that of the 12-in.-wide specimen. This is the so called ΔT hypothesis which has been mentioned as being satisfactory for comparing groups of steels within a grade.

Using the two above-mentioned relations between different types of specimens, it is possible to combine the data from Figs. 5, 6, 7 and 8 into Fig. 9 where the two zones are shown. On the left are the safe steels at transition temperatures below −40; on the right are the unsafe steels at transition temperatures above +40, and in the middle a questionable zone. If all steels produced had transition temperatures which fell in the zone to the left, practically no structural failures would occur in ship hulls; whereas, if all the steel production fell in the zone to the right, we would have a structural failure problem equal to or greater than that which occurred on the Liberty Ship and T-2 tankers during and since World War II.

Figure 10 shows a curve running from +120 to −50° F. which represents the effectiveness of performance standards using the 12-in.-wide specimen. The curve shown involves two assumptions: first, that the range of notch toughness of the steel supplied corresponds to that produced during World War II and second, that the ship operating conditions are similar.

If the above-assumed conditions prevail and if the acceptance standard is established at a level equivalent to transition of the 12-in.-wide specimen at +120° F., then none of the steel would be rejected and the likelihood of fractures would remain unchanged. On the other hand if the standard were equivalent to the 12-in.-wide specimen at −50° F., fractures would not be expected even at Liberty hatch corners. Of course there would be no acceptable steel at the lower end. An

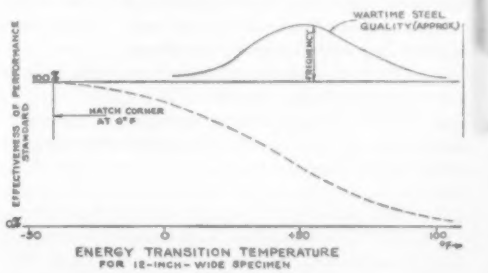

Figure 10

intermediate point would be selected for a specification standard if steel quality remained unchanged, and a practical percentage of rejection would be anticipated.

The ultimate selection of a performance standard will depend of course on other factors, such as the degree to which it appears feasible to improve mill techniques and thereby provide a plentiful supply of notch-resistant steel, the question of supply and demand both in war and in peace, and the consequent cost. These factors will probably be compared with a curve such as that shown in Fig. 10 when the ultimate selection of performance standard is made.

Elsewhere in the paper it is indicated that the operating stresses in the ships hulls are reported as being low, and therefore, it is deduced that the stress concentration aboard ship is more severe than in the wide plate tests. This deduction is erroneous because increasing the width of the plated structure reduces the nominal stress required to start fracture and even for the slotted plate specimens nominal failure stress values as low as 28,000 psi. have been reached. In addition, it should be pointed out that the operating stresses reported are nominal values obtained by dividing a bending moment by the section modulus of the hull girder. This does not give the total stress value because the actual stress present is made up of stresses from a variety of sources in addition to the static or wave bending moment and in most cases only the static moment due to cargo load distribution was reported. Stresses from load distribution, wave bending moment, vibration, temperature differential and locked-in stresses due to fabrication must be added and multiplied by a concentration factor to obtain the total stress at any location in the ship's hull; and this will be much higher than the nominal stress reported. Preliminary estimates have shown that this combined stressing is easily capable of providing the stress level and the potential energy for cracking but this is a probability study of considerable complexity.

The foregoing discussion of the paper may be summarized as follows:

1. Higher energy absorption is believed to be involved in brittle fracture propagation in ship plate than was supposed by the authors. The lower (so-called "ductility") transition temperature is not significant in 12-in.-wide plate tests, nor in shipboard fracture propagation. Considerable data in the form of comparative thickness reduction measurements in plates from fractured ships and from laboratory tests of 12-in.-wide specimens appear to support these conclusions.
2. The 12-in.-wide slotted plate is a suitable basis for notch sensitivity comparisons.
3. Stresses in ship hulls are sufficiently high to initiate cracks and to supply the potential elastic energy required for their propagation.

Authors' Closure

The line of reasoning used by Mr. MacCutcheon and the other discussers of our paper is quite different from ours, and these divergent ways of viewing the brittle fracture problem should therefore be examined further.

Figure 9, which summarizes many of the conclusions reached by the discussers, is based upon three premises:

1. That the energy transition temperature (the fracture transition temperature in this case) as evaluated by hatch corner tests truly indicates the critical temperature for safe service performance.
2. That the temperature at 15 ft.-lb. on the Charpy V-notch curve also indicates the critical temperature for safe or unsafe service performance as the case may be.
3. That the so-called ΔT hypothesis may be used to convert the results obtained with the above specimens to results obtained with 12-in.-wide plate specimens.

Accordingly, they subtracted 40° F. (difference between hatch corner and 12-in.-wide specimen) from 0° F. (the minimum temperature usually experienced in service) and found the maximum safe transition temperature (−40° F.) for steels by the 12-in.-wide specimens. Similarly, they assumed a difference of 20° F. between the 15 ft.-lb. Charpy V-notch temperatures and the 12-in.-wide plate transition temperatures and arrived at 40° F. as the minimum 12-in.-wide plate transition temperature for unsafe steels, based upon the Charpy V-notch data of their Fig. 6.

Discussing premise 3 first, we are convinced that the ΔT hypothesis is invalid, even for "groups of steel within a grade," when the criteria for determining transition temperatures are indiscriminately mixed as they are here. The temperature at the 15 ft.-lb. level on the Charpy V-notch curve (we used the 10 ft.-lb. level in our evaluations) involves consideration of a low energy level, and, as we pointed out in the paper, may be associated with a ductility transition. Most of this energy is used in *initiating* the crack. The temperature selected for the 12-in.-wide plate specimens was a fracture transition temperature, which is the highest temperature at which *rapid propagation* of the crack takes place. Not all factors affect the fracture and ductility transitions in the same manner; hence, it must be decided which transition, if any, will be used for evaluation, because the relative ratings of the steels will depend upon this choice. For example, Enzian and Salvaggio[1] found that nitrogen affected the fracture transition temperature appreciably but had little or no effect on the ductility transition. We have found this same behavior and have further observed that fissuring (the transverse stresses present during testing apparently cause the metal to part along planes of weakness, e.g., near long inclusions, and hence give rise to "fissures") has a much more decided effect on the fracture transition than on the ductility transition. Project steels A and C provide a classic demonstration of the same principle. On the Charpy V-notch curve, the temperatures for both these steels were about 50° F. at

the 15 ft.-lb. level. By the 12-in. plate tests at Swarthmore,[2] their transition temperatures were, respectively, 50 and 94° F. Such a rough correlation between these tests (as a result of the mixed criteria) seems to preclude the use of any ΔT hypothesis.

In our opinion, the fracture transition temperature in the hatch corner test (corresponding to the temperature at which the large drop in energy occurs) and the temperature at 10 ft.-lb. on the Charpy V-notch curve should not both be set up as being capable of evaluating ship behavior, for they are widely at variance with each other, and the ΔT hypothesis should not be used for the reasons stated above. Yet it is our understanding that the only proven test is the Charpy V-notch test, in which a definite correlation was found with failures in service. Therefore, premise 1 must be considered untenable in view of such evidence. This is not to imply that there is anything wrong with the hatch corner test itself, but we would have interpreted the results somewhat differently by selecting the critical temperatures at much lower energy levels than those associated with the fracture transition.

Premise 2 is in line with our thinking. Figure 6, as well as indicating unsafe steels, implies that steels with 15 ft.-lb. Charpy V-notch temperatures below 20° F. (or below 60° F. if just the plates in which fracture started are considered to be the controlling factor) would be safe for ship service.

We have already stated our belief that many small cracks are present in a welded ship structure, and that these stress raisers may well be the source of brittle failure. Such cracks may propagate rapidly in a ship at quite high temperatures, higher than those indicated by the temperature at 15 ft.-lb. on the Charpy V-notch curve, *provided* sufficient energy is available to start this rapid propagation. But all of the information that has been obtained on ship fractures and the service experience with the ships themselves indicate to us that only a relatively low amount of energy is available to start crack propagation. The ship therefore does not break until the temperature is low enough for the available energy to exceed the energy required to start crack propagation. If the service conditions were more severe and hence the available energy greater, brittle failures would probably occur at higher temperatures than those involved in the failures being considered. When relatively low amounts of energy are to be absorbed, such absorption can take place by deformation around a notch or sharp crack without rapid crack propagation taking place. Even slow extension of an already existent crack can be tolerated. Such deformations absorb energy and protect the structure. It is only the rapid crack propagation that is dangerous.

We would again point out that the thickness reductions in the wide plate tests for many of the cleavage failures are quite different from those involved in actual ship failures. The discussers state that the thickness reductions at the fractured edge of the wide plate specimens for the cleavage failures are within the same range, which is usually 1 to 3%, as those measured on the edges of fractures in ship hulls. It is our understanding that in ships very little reduction in thickness was found near the origin of the fracture, yet this was not the case in most of the wide plate tests even for cleavage failures. The authors believe that the deformation occurring prior to cleavage failure in the wide plate tests is quite important, since it indicates that the temperature is sufficiently high to permit such deformation before the cleavage failure takes place. In ships, cleavage fractures could have occurred at temperatures all the way up to the fracture transition temperatures of the steels involved, and it is very likely that under such conditions the deformations around the notches would have been greater than those that were obtained. Actually, however, the available data indicate the failures occurred at temperatures well below the fracture transition temperature with very small accompanying strains. Therefore, it does not seem valid to select the fracture transition as the criterion of performance and conclude that the deformation around the notch is unimportant, when a correspondence of test and service behavior could have been obtained by selecting lower temperatures on the wide-plate-test performance curve. Moreover, in many of the wide plate specimens that failed by cleavage, the thickness reduction at appreciable distances from the notch was more than the usual 2% experienced in service, which further indicates that the temperatures of these tests are too high to reproduce service behavior.

In Table 1 of our paper, a 72-in.-wide plate test on Project steel C at 78° F. (cleavage failure) showed 11.5% reduction 1 in. from the notch and 4% at 16 in. from the origin of failure. At 80° F., a similar test showed 5 and 6% reduction 16 in. from the origin. At 31° F., the reductions are more in line with those observed in actual failures. These observations accord with our interpretation of the results obtained on Charpy V-notch specimens. By this Charpy specimen, the critical temperature (at 10 ft.-lb.) is about 40° F. for steel C. The wide plate test at 31° F. should, therefore, represent the type of behavior that might occur in a ship, whereas the test at 78° F. should not.

Project steel D, containing 0.20 C, 0.55 Mn and 0.20 Si, showed 5.0 and 5.5% thickness reduction 16 in. from the notch and 18% at $^1/_4$ in. from the notch in a 72-in. plate test at 34° F. (cleavage failure).[3] Steel N, containing $3^1/_2$% Ni, showed 3% reduction at 4 in. and 13% at $^1/_8$ in. from the notch in a 12-in.-wide plate test at −78° F. (cleavage failure).[3] Nevertheless, the energy absorbed in this failure was almost equal to that absorbed by steel C when it failed entirely by shear. Is not this energy also important regardless of the mode of failure? Our answer to this would be in the affirmative. And our answer to the question whether the large energy transitions (fracture transitions) in the wide plate tests were significant with respect to service behavior would be in the negative, partly because of the reasons stated above.

We can readily understand why the discussers are reluctant to give the name "ductility transition" to

energy drop-offs that are hardly noticeable. If, however, a drop-off is present and it coincides with the disappearance of shear fracture under the notch, we would see no reason for not accepting such terminology. In any case, the behavior would be that required by definition, and we did try to define what we meant by ductility transition. If the behavior did not satisfy this definition, we would not call it a ductility transition. For example, we did not speak of a ductility transition at 10 ft.-lb. for the Charpy V-notch specimen. We simply spoke of a certain temperature associated with this low energy level. It might also be better not to refer to a ductility transition in the wide plate tests. If a ductility transition did not exist in this instance, we would refer only to a temperature at a certain low energy level, as we did in connection with our Fig. 10.

It was our impression, however, that even in the wide plate tests a small amount of shear failure usually occurred just below the notch at temperatures well below that of the fracture transition. This impression was based upon examination of photographs of the fractured specimens and upon examination of some of the specimens themselves. Moreover, in the Swarthmore Report[2] on the 12-in.-wide plate tests, the tables list the first visible crack as occurring at loads well below the maximum even for specimens that reportedly broke with cleavage failures. Since cleavage failures are usually associated with rapid crack propagation and shear failure with slow propagation, it seems very likely that the initial small extension of this crack, which occurs slowly, takes place in the shear mode. Regardless of whether or not an actual ductility transition occurs in one of these tests, it is important to establish a level of energy in the test which is in keeping with the critical amount necessary to assure satisfactory service performance at operating temperatures. Furthermore, it is believed that the temperature associated with this critical amount of energy should always be used in evaluating materials, regardless of where this temperature lies in respect to the fracture transition temperature.

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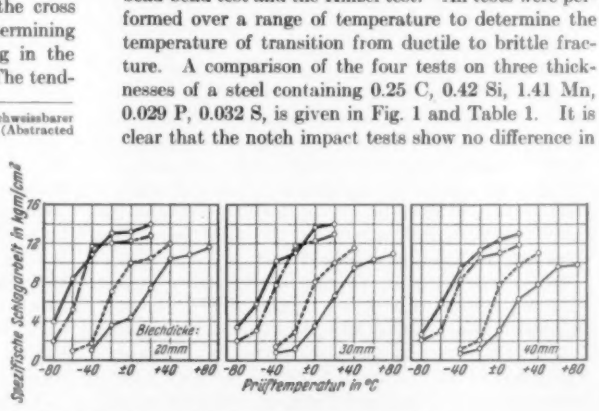
Testing the Tendency of Weldable Structural Steel Toward Brittle Fracture*

by E. Folkhard

THE basic requirement for testing steel for brittle fracture is that the steel be tested in the same condition as it is to be used in the welded structure. Welding creates a hardened heat-affected zone and produces multiaxial shrinkage stresses over the cross section. The shrinkage stresses are the determining factor for brittle fracture, whereas hardening in the heat affected zone is responsible for cracks. The tendency toward cracks and the tendency toward brittle fracture are two fundamentally different properties of a steel.

Four tests were used to determine their suitability for detecting tendency toward brittle fracture. The four tests were the notch impact test, the Schnadt test, the bead-bend test and the Kinzel test. All tests were performed over a range of temperature to determine the temperature of transition from ductile to brittle fracture. A comparison of the four tests on three thicknesses of a steel containing 0.25 C, 0.42 Si, 1.41 Mn, 0.029 P, 0.032 S, is given in Fig. 1 and Table 1. It is clear that the notch impact tests show no difference in

* Abstract of "Die Prüfung der Sprödbruchempfindlichkeit schweissbarer Baustähle," published in *Stahl u. Eisen*, **71**, 347–351 (1951). (Abstracted by Dr. G. E. Claussen.)



Vertical axis, energy to fracture, mkg./cm.²; horizontal axis, temperature of test, ° C.
Left diagram, 0.78 in. thick; middle diagram, 1.18 in. thick; right diagram, 1.58 in. thick
—— DVM specimen 10 × 10 mm., notch diameter = 2 mm., notch depth = 3 mm. (heavy full line)
—— DVM specimen 10% cold-work then aged at 480° F. (light full line)
—— Schnadt specimen, 0.5 mm. notch radius
- - - - Schnadt specimen, 0.025 mm. notch radius

Fig. 1 Notch impact and Schnadt results for three thicknesses of a steel (see Table 1)

Table 1—Comparison of Kinzel and Bead-Bend Test Results on Three Thicknesses of the same Steel (See Fig. 1)

Temperature of test, ° C.	Plates 0.78 in. thick: Bead-bend angle, degrees	Plates 0.78 in. thick: % Contraction in Kinzel specimen	Plates 1.18 in. thick: Bead-bend angle, degrees	Plates 1.18 in. thick: % Contraction in Kinzel specimen	Plates 1.58 in. thick: Bead-bend angle, degrees	Plates 1.58 in. thick: % Contraction in Kinzel specimen
−20	35 brittle	4.6	13 brittle	0.8	14 brittle	0.9
−10	68 ductile	6.3	11 brittle	0.7	15 brittle	0.8
0	>150	6.5	14 brittle	1.3	12 brittle	0.8
+10	>150	6.2	27 brittle	4.7	16 brittle	0.9
+20	>150	7.1	82 ductile	6.8	22 brittle	1.9
+35			89 ductile	7.2	46 mixed	3.6
+50			>150	6.7	92 ductile	5.4

Steels A, B, C and D in order from left to right. The four lines in each graph have the same significance as in Fig. 1

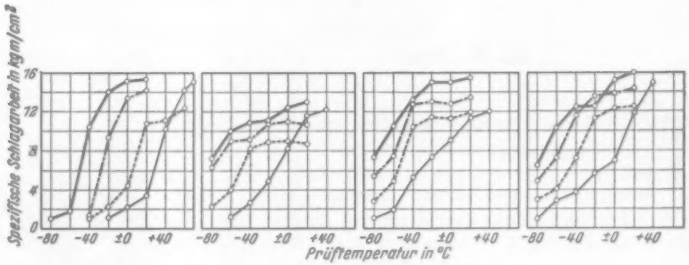


Fig. 2 Notch impact and Schnadt results for four steels (see Table 2)

Table 2—A Comparison of Bead-Bend and Kinzel Tests on Four Steels (See Fig. 2)

	Steel A	Steel B	Steel C	Steel D
% C	0.12	0.15	0.18	0.22
% Si	0.05	0.25	0.41	0.48
% Mn	0.33	0.91	1.30	1.47
% P	0.029	0.024	0.036	0.029
% S	0.027	0.031	0.027	0.022
Yield point, psi.	29,300	45,500	53,000	61,500
Tensile strength, psi.	52,600	69,000	82,000	97,000
% Elongation	33.8	32.6	31.2	27.2

Temperature of test, ° C.	Bead-bend angle, degrees	% Contraction in Kinzel specimen	Temperature of test, ° C.	Bead-bend angle, degrees	% Contraction in Kinzel specimen	Temperature of test, ° C.	Bead-bend angle, degrees	% Contraction in Kinzel specimen	Temperature of test, ° C.	Bead-bend angle, degrees	% Contraction in Kinzel specimen
−20	>150	6.3	−20	>150	7.2	−20	15 brittle	0.9	−20		
−10	>150	6.8	−10	>150	6.8	−10	32 brittle	6.2	−10		
0	>150	6.5	0	>150	6.8	0	>150	6.9	0	12 brittle	0.6
10	>150	7.1	10	>150	7.1	10	>150	7.2	10	21 brittle	1.3
20	>150	6.6	20	>150	7.3	20	>150	7.1	20	34 brittle	5.8
35			35			35			35	75 ductile	6.4
50			50			50			50	81 ductile	6.2

tendency to brittle fracture among the three thicknesses, but that the Kinzel and bead-bend tests show the superiority of the thinnest over the thickest plate.

Another comparison of the four tests on steels 1.58 in. thick is shown in Fig. 2 and Table 2. The steels were tested in the normalized condition. Steel B was killed with aluminum to produce fine grain. Whereas the higher tensile steels are superior to Steels A and B in the notch impact and Schnadt tests, the reverse is true in the bead-bend and Kinzel tests.

Automatic Welding with Flux Shielding (the Elin Chain System)*

by W. Senft

THE chain-flux system of automatic arc welding is illustrated diagrammatically in Fig. 1. A bare electrode is fed by rollers through a contact shoe, after which semicircular flux is pressed against the wire. Two fingers hold the flux against the wire just above the arc, Fig. 2. The welding head is provided with an eccentric to produce weaving motion of the electrode back and forth across the joint.

The chain flux may have the same composition as the coating on manual electrodes, or may have a special composition particularly suited for a given application. Each element of the chain is about $^5/_8$ in. long and is reinforced by two fine wires shown as black dots in Fig. 3. The chain is extruded in special presses, Fig. 4. Roller 8 produces notches in the extruded flux. After drying, the flux is rewound and the flux then breaks into short lengths at the notches.

The chain-flux system is recommended for welds requiring high ductility. A special apparatus has been developed for shipyard welding.

* Abstract of "Der Elin-Mantelkettenschweissautomat," published in *Elin Zeitschrift*, 3, 35–39 (March 1951). (Abstracted by Dr. G. E. Claussen.)

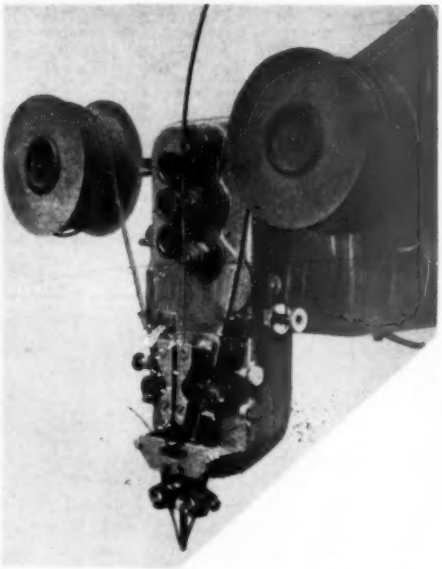


Fig. 2 The chain flux automatic arc welding head

Fig. 3 Profile of the chain flux

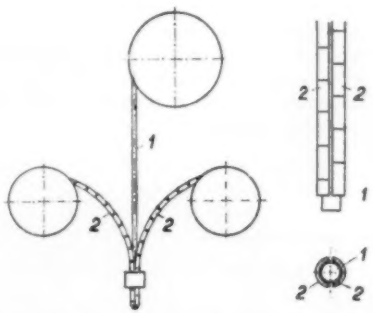


Fig. 1 Sketch illustrating the chain-flux system of automatic welding. 1, bare welding wire; 2, chain flux

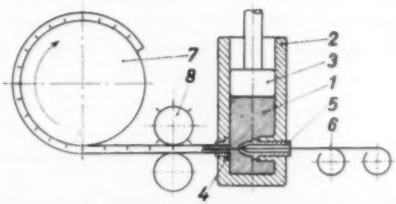


Fig. 4 Sketch illustrating the extrusion of the chain flux

1, flux to be extruded; *2*, cylinder of extrusion press; *3*, piston of extrusion press; *4*, extrusion die; *5*, guide for the two fine wires; *6*, coils of fine wire; *7*, reel of chain flux; *8*, rotating knife to notch the flux

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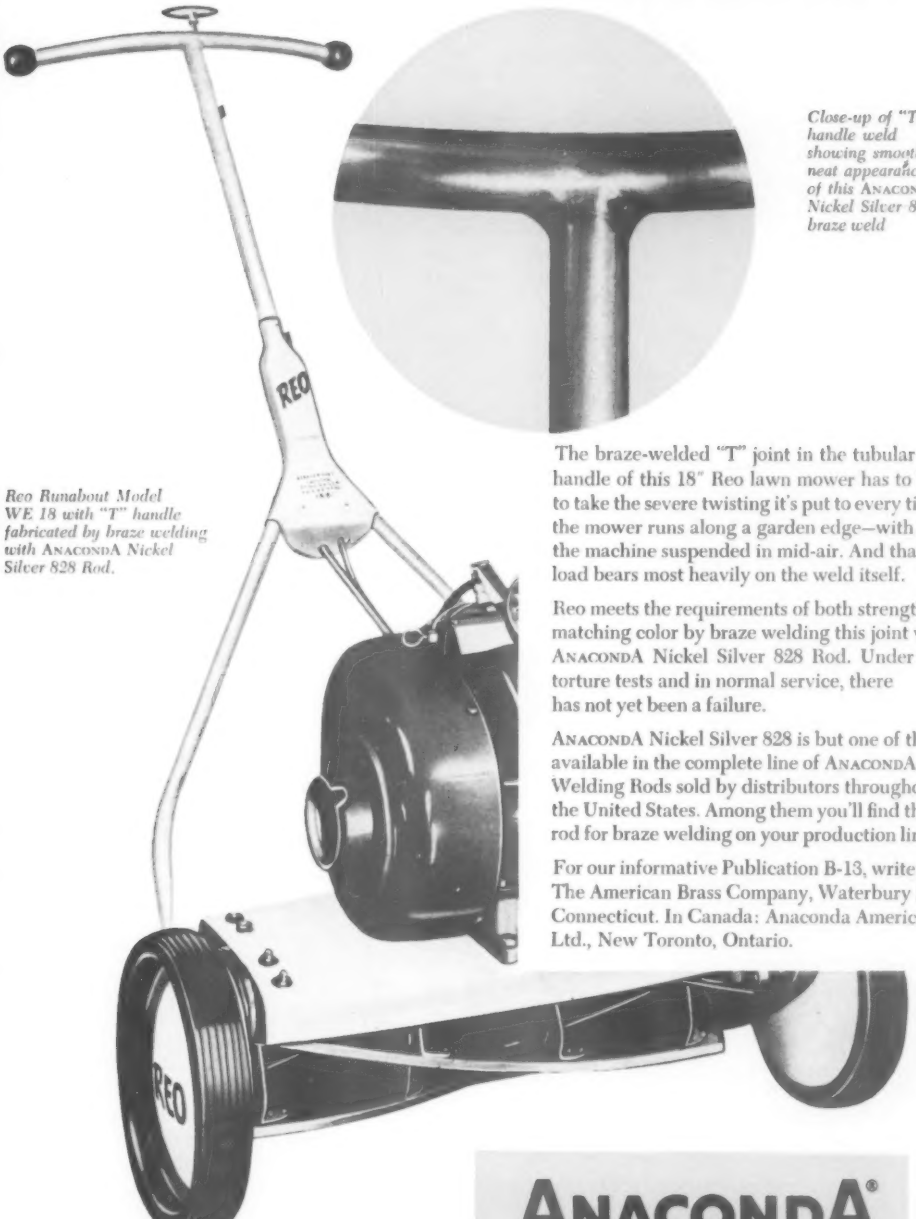

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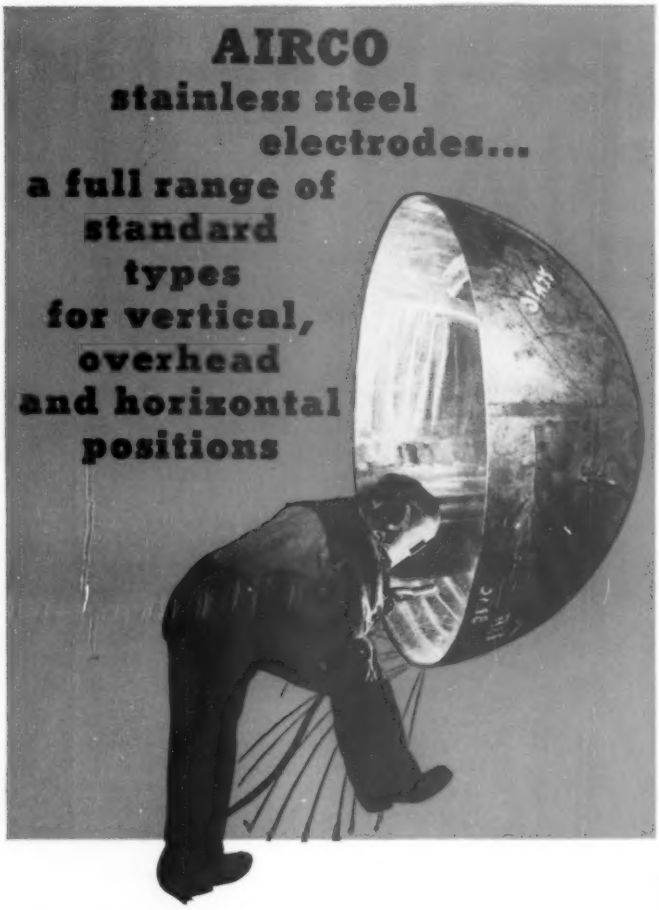

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